

METALLURGIA

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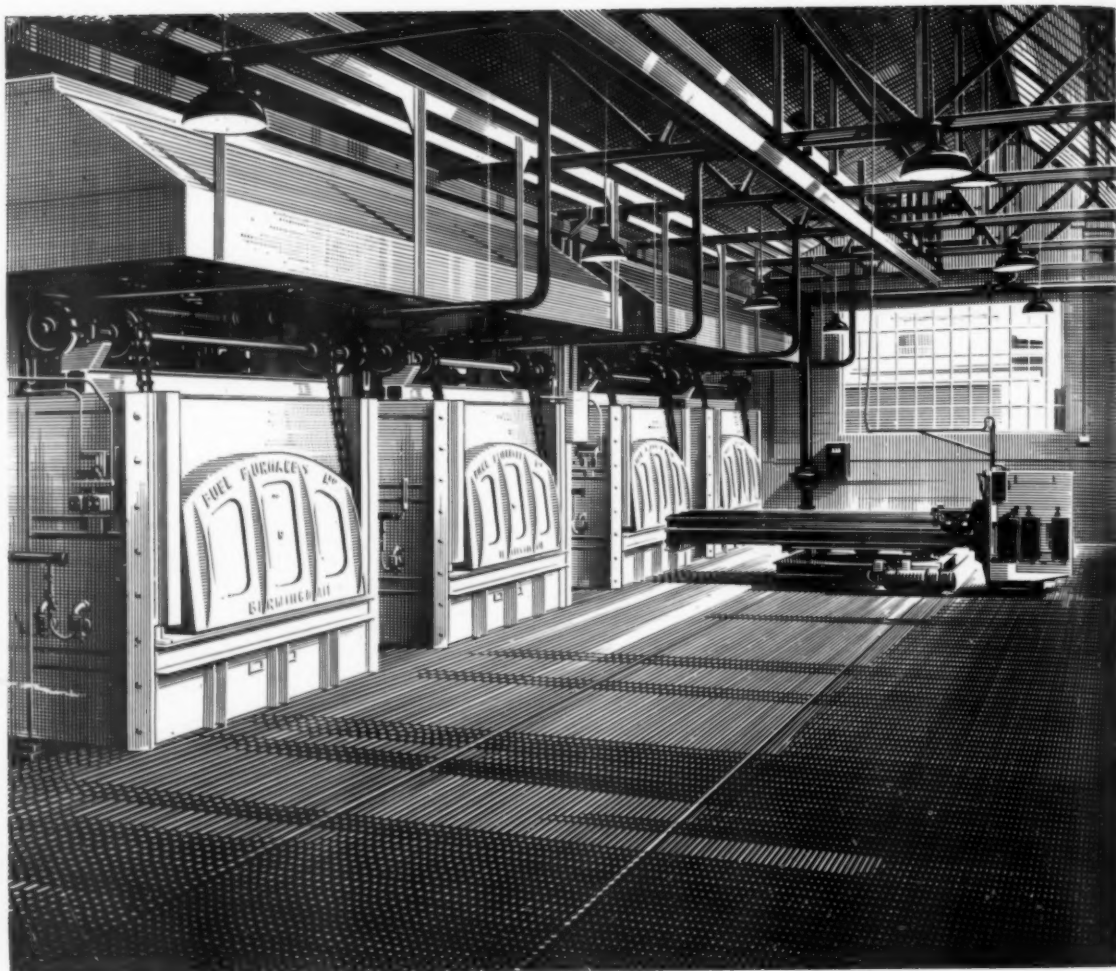
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METALLURGIA

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INCORPORATING THE METALLURGICAL ENGINEER

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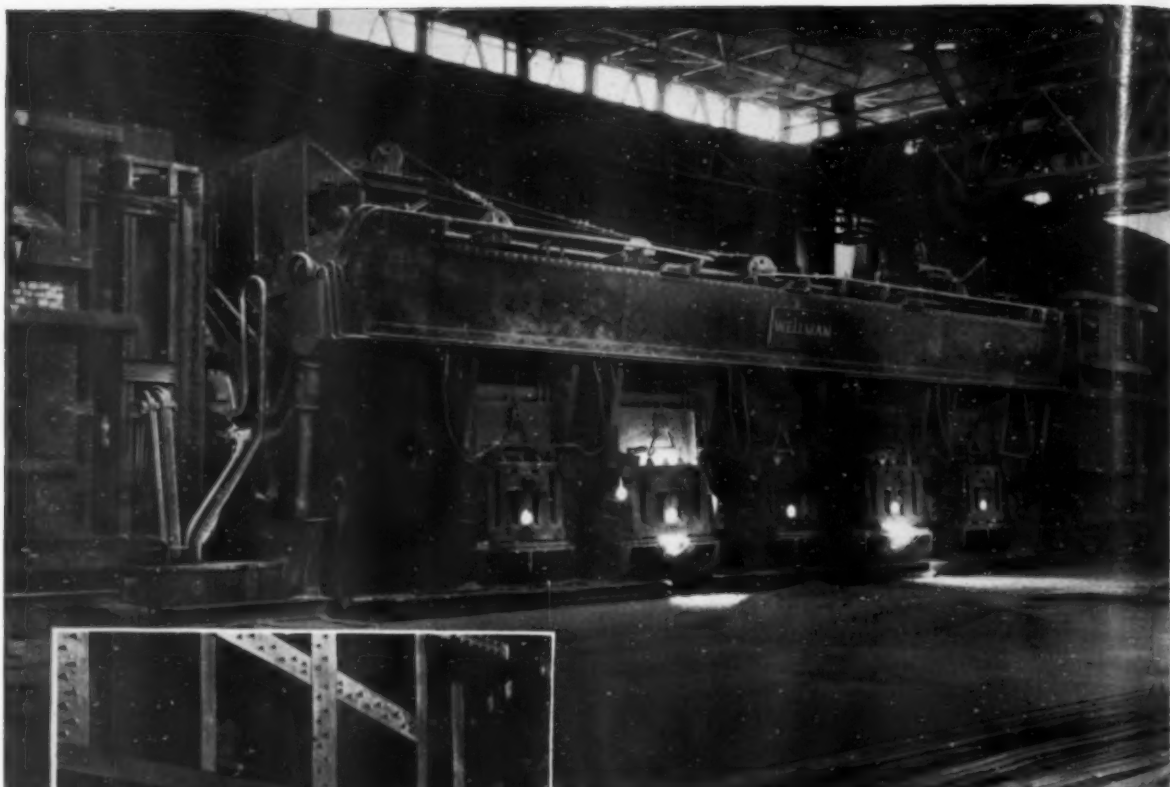
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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE "METALLURGICAL ENGINEER"

APRIL, 1957

Vol. LV. No. 330

Rises without Strings?

THERE is always a risk in writing about current affairs—even in a newspaper where the time interval between writing and publication is short—that a sudden turn of events will alter the whole situation. At the time of writing, the country is faced with a state of industrial strife such as it has not experienced for some years. One strike is already in being and another is awaiting zero hour, while the situation in a third major industry—the nationalised railways—is potentially dangerous. By the time this appears in print, the situation will have changed considerably—for the better, it is to be hoped. The mere fact of work being resumed is not enough; some positive action must be taken to guard against a repetition. The fundamental causes of the disputes must be established and a solution sought which will eradicate them.

The wage structures of many of our modern industries are so complex that comment on the detailed arguments put forward by the employers and unions, respectively is difficult for an outsider. A number of general issues are raised, however, which are also the concern of industries other than those involved in the present disputes. There is for instance the suggestion, implied in a statement attributed to Mr. E. J. Hill, General Secretary of the United Society of Boilermakers, that strikes are a private affair between bosses and unions. Mr. Hill is paid to look after the interests of the members of his union, but whether he really believes that the question of exports has no bearing on the welfare of his members—as was inferred from the statement to the effect that he was not worried about the effect of the strike on exports, but only about its effect on the unions' pay claim—is difficult to judge without further information on the circumstances under which the remarks were made. Most people have no doubt, however, that, as the Prime Minister said at Leicester, "...today, with all the pressures on our economy, these (industrial disputes) are matters of national concern. The only beneficiaries of these troubles are our competitors."

Quite apart from the overall effect on the national economy, the strikers in the shipbuilding industry endeavoured to involve workers only indirectly concerned with shipbuilding, as witness the Southampton dock strike which sprang up over the sailing of the *Queen Mary*. An almost ludicrous situation arose in Liverpool, where decorators at work on a city building were forced to strike in sympathy with the shipyard workers because the firm employing them also undertakes ship decorating.

These are no more than regrettable by-products of the main dispute, however, and it is to the origins of the latter that one must look for guidance on future behaviour. When, a year ago, settlements for higher wages were made in the engineering and shipbuilding industries, the unions promptly gave notice that they would present another claim as soon as they thought the time opportune. The employers immediately declared that it would be

rejected. Thus, both sides were already committed to definite lines of conduct, which, if adhered to, could only lead to strife. If to climb down and recognise a mistaken attitude is always to be regarded as weakness, then the sooner both sides learn to refrain from making unguarded statements, the better. But were they unguarded, or was there a determination to force a showdown.

The unions' claim for higher pay is based on two factors—the rise in the cost of living and the prosperity of the industry. In some industries, including the steel industry, wages are geared to the cost of living, but automatic cost-of-living rises can only lead to higher prices unless other changes, such as an increase in productivity take place concurrently. The danger from higher prices is twofold; they increase still further the cost of living at home, and they make it more difficult to meet the ever growing competition in the export markets.

In the case of an industry where prosperity is increasing, there is some justification for the union view that the wage-earner should benefit from that increase, for industry is a partnership between capital and labour, neither being much use without the other. The four claimants to a share in the profits are the Government (by taxation), the company (by ploughing back), the shareholders (by dividends), and the workers (by wages). As far as the workers are concerned, whether variations in prosperity can best be expressed in terms of variations in wages is not at all certain. It is a comparatively easy matter to increase wages when profits rise, but it is questionable whether a decrease would be acceptable in a poorer year. It may be that some form of bonus scheme or profit-sharing would be a better proposition, the basic wage being supplemented by a factor, payable weekly or as one or more lump sums, which is related to profits. How the profits should be shared amongst the various claimants would leave room for much detailed discussion, but that would be a matter for negotiation.

Each time agreement is reached on a wages dispute the pious hope is expressed that the unions' will help to raise productivity, but no firm commitments are made, and very little appears to be done. In many cases, considerable improvement could be achieved by the abandoning of restrictive practices. The demarcation disputes between unions, which are so rife in the shipbuilding industry, and the refusal to operate new machinery at full capacity for fear of redundancy are outstanding examples. Reference was made earlier to the fact that wages in the steel industry are geared to the cost of living; it should also be pointed out that productivity in the industry has increased considerably since the war, as a result of a more enlightened outlook on the part of the worker than prevails in many other industries. If the present troubles can lead to the idea of linking productivity with wage increases, we may be on the way towards more settled industrial conditions and increased prosperity for the nation as a whole.

Personal News

MR. R. A. MILLER, Sales Director of Foundry Services, Ltd., has left on a world tour involving a 50,000 mile flying schedule. He is to visit India, Kenya, South Africa, Australia, and New Zealand, before making his third visit to Japan in twelve months. On his homeward journey, Mr. Miller intends spending some days in Hong Kong.

MR. A. M. SAGE has been appointed Manager of the newly formed Development Department of British Electro Metallurgical Company. For a period, he will continue to be responsible, in a consultant capacity, for the British Iron and Steel Research Associations' work on structural steels.

HONEYWELL-BROWN, LTD., announce the appointment of MR. W. R. OWEN as Manager for the North East Region. He is succeeded as Manager of the Sheffield Office by MR. A. HAGUE, his deputy for the past three years. MR. HALSTED and MR. GABE, both of whom joined the Company three years ago, have been appointed Managers of the Middlesbrough and Cardiff Offices, respectively.

MR. H. MORLEY has relinquished his position as Work Study officer to The United Steel Cos., Ltd., in order to take up an appointment as Works Manager (Services) to Samuel Fox & Co., Ltd. MR. J. H. D. KERSE becomes Acting Works Study Officer to United Steel.

METROPOLITAN-VICKERS ELECTRICAL CO., LTD., announces that MR. E. H. BEECH has been appointed Superintendent, Foundries and Pattern Shop. Mr. Beech who is this year's President of the Institute of British Foundrymen (Lancashire Branch) succeeds MR. A. PHILLIPS, who remains with the Company in an advisory capacity.

MR. GRAHAM COOKE has been appointed Advertising and Publicity Director of the Solartron Electronic Group, Ltd., having been elected a Director of Solartron Laboratory Instruments, Ltd.

TUBE INVESTMENTS, LTD., announces that the RT. HON. THE LORD CLITHEROE, P.C., has joined the Board.

MR. W. H. ROGERS has been appointed Industrial Sales Manager of British Oxygen Gases, Ltd.

THE MOND NICKEL CO., LTD., announces that MR. L. K. BRINDLEY, Deputy Chairman of the Company and of Henry Wiggin & Co., Ltd., and MR. A. PARKER HAGUE, a Director of the two Companies, having reached retirement age, have relinquished their appointments effective February 28th, 1957.

MR. R. WATKINS has been appointed to represent the Cambridge Instrument Co., Ltd., at 7 Norfolk Court, Norfolk Street, Glasgow (Tel. South 0349) and will handle all enquiries and consultations regarding new instruments. MR. S. J. STEEL will continue to handle all matters relating to repairs and service.

MR. B. BUTCHER, Organising Superintendent and Labour Manager of Samuel Fox & Co., Ltd., a subsidiary of The United Steel Cos., Ltd., has been appointed a Director of the Company, which he has served for 52 years.

MR. J. I. CRABTREE, the well-known authority on photographic chemistry, has retired after 43 years with the Eastman Kodak Company Research Laboratories. British-born, Mr. Crabtree was Assistant Head of the

Applied Photography Division of the Eastman Kodak Research Laboratories.

MR. J. A. LAMOND has been appointed Joint Managing director of W. H. A. Robertson & Co., Ltd., of Bedford. MR. M. F. DOWDING, Engineering Sales Manager of Davy and United Engineering Co., Ltd., has been appointed a Director of Davy-United's Middlesbrough subsidiary, Davy and United Roll Foundry, Ltd., manufacturers of rolls and steel castings.

PROF. G. WESLEY AUSTIN has accepted an engagement as Consulting Supervisor to the Metallurgy Division of B.I.S.R.A. He will be responsible for the general supervision of the metallurgical research programme on behalf of the Metallurgy (General) Panel of the Association.

MR. E. G. P. HINDS, Foundry Services overseas Technical Representative for the Benelux countries, has left for Portugal where he is to make an intensive study of the foundry industry. The Company already does considerable business in its Fosco products, to improve castings, through active local agents. Mr. Hinds will be working in close association with them.

MR. E. BOLTON, Chairman and Managing Director of the Solartron Group, is at present on a five weeks visit to New York, Philadelphia, Washington, Los Angeles, Chicago, Dayton, Cleveland, Boston and then Montreal and Ottawa.

MR. K. G. SINCLAIR has been appointed Chairman of Griffin & George, Ltd., in succession to MR. R. MCKINNON WOOD, O.B.E., who asked to be relieved of his duties in the office in view of the important public duties he will assume as Chairman of London County Council.

Obituary

We regret to record the death of the following :—

MR. H. W. P. MATTHEY, Chairman of Johnson, Matthey & Co., Ltd., who died on March 6th, 1957, at the age of eighty. Mr. Matthey joined the Company in 1894 and became a Director four years later. He became Chairman of the Company in 1928, and presided over its destiny throughout the difficult periods of the depression, of the second world war, and of the reconstruction that followed.

MR. A. E. GRIFFITHS, Chairman of Modern Furnaces and Stoves, Ltd., who died at his home, Milverton Grange, West Park Road, Smethwick, on Friday, March 1st, 1957.

DR. PAUL GRODZINSKI, who died on February 20th, 1957, at the age of fifty-six. Born in Berlin, Dr. Grodzinski came to England in 1938, and in 1940 he became Technical Editor of *The Industrial Diamond Review*, a position he held until his death. In 1943, he took up an appointment with the Diamond Corporation, as Head of the Industrial Diamond Information Bureau, in which capacity he was responsible for the publication of *The Bibliography of Industrial Diamond Applications*. Dr. Grodzinski was particularly interested in hardness testing and a number of articles on the subject have appeared in *METALLURGIA* under his name. His inventions included a double-cone diamond indenter. In September 1955, he became a Doctor of Engineering of Brunswick Technical University, and a paper on hardness testing, based on his doctorate thesis, earned him full membership of the Institution of Mechanical Engineers.

Some Observations of the Effect of a Dispersed Oxide Phase on the Recrystallization of Copper

By J. W. Martin, M.A., Ph.D.

Department of Metallurgy, University of Cambridge

Activation energies for recrystallization (Q_R) of pure copper, copper containing silicon in solid solution, and copper containing dispersed silica particles have been compared, the progress of recrystallization being followed microscopically and by hardness measurements. Q_R is lowered by an amount increasing with silica content, and a similar effect was observed with decreasing grain size in unalloyed copper. The results are discussed in terms of local lattice distortion produced at the particle-matrix interface by plastic deformation.

SEVERAL reviews have been published recently (e.g.^{1, 2, 3}) considering the changes and mechanisms involved during the annealing of cold-worked metals. Little detailed work appears to have been carried out on the variables controlling the processes. The effect of solute elements on recrystallization characteristics was first investigated by Stanley⁴ in the case of silicon ferrite. More recently, Phillips and Phillips⁵ used hardness measurements to investigate the effect of some solute elements on the recrystallization of copper, and Perryman⁶ has investigated some aluminium-magnesium alloys.

Little work appears to have been done on the effect of a dispersed phase on recrystallization, and in the work described below, a technique involving the internal oxidation of dilute alloys of silicon in copper has been employed to produce oxide dispersions. This is a technique whereby oxygen is allowed to diffuse into the alloy at elevated temperature: the solute metal is oxidized, and the resulting structure consists of a dispersion of base metal oxide in a matrix of pure copper.

Martin and Smith have investigated the fatigue⁷ and creep⁸ properties of internally oxidized copper, and have reviewed briefly⁷ a number of previous researches concerned with the mechanical properties of internally oxidized materials. Plastic deformation usually leads to intergranular failure of these materials^{7, 9, 10}, due to oxide particles being concentrated in the grain boundaries as well as dispersed within each crystal. In the present work, single crystal specimens have been employed in order to overcome this difficulty.

The recrystallization characteristics of pure copper, copper containing silicon in solid solution, and internally oxidized materials have been compared. Specimens have been deformed and recrystallized under various conditions, and the progress of recrystallization has been followed microscopically and by hardness measurements.

In addition, the mean size of the dispersed particles has been estimated; this was determined by an electron microscope examination of extracted particles.

Preparation of Specimens

Copper was chosen as the basis metal as being the most noble metal available in large enough quantities at a

reasonable cost, and silicon has been the base metal used in dilute solution. The copper was supplied by Imperial Chemical Industries, Ltd., Metals Division, Birmingham, in the form of a 27-lb. slab of commercial tough-pitch quality. The following results of spectrographic analysis were provided by the suppliers:

Iron	< 0.01%
Nickel	Slight trace
Antimony ..	> 0.002%
Bismuth ..	> 0.001%
Arsenic ..	> 0.005%
Oxygen ..	0.04% (approx.)
Zinc	} Not detected.
Tin	
Lead	
Manganese ..	
Aluminium ..	
Silicon ..	
Phosphorus ..	

The alloys were prepared by melting 500 g. of the copper in a crucible, heated in a gas-fired injector furnace. The molten metal was protected from oxidation by a layer of wood-charcoal on the melt. The requisite amount of silicon was added to the crucible, and the alloy cast into a metal mould. Analysis of the alloys prepared yielded the following results:

Si ₁	0.051% silicon.
Si ₂	0.25% silicon.

GROWTH OF CRYSTALS

The crystals for test were grown in the graphite mould illustrated in Fig. 1. It was designed to produce parallel-sided crystals, which could subsequently be given reproducible compressive strains by deformation in a rolling mill. The mould *M* consisted of a graphite rod, about 0.6 in. in diameter, in which a slot 0.1 in. wide had been milled to a depth of 0.8 in. The copper was rolled to a thickness such that it would just fit into the slot, and a specimen *S* was cut so that the slot was exactly filled by the metal. The metal and mould were then pushed into the graphite tube *T*, which fitted closely, and the end was sealed by means of the tight-fitting plug *P*. This plug was pushed into *T* until it abutted against *M*.

The crystals were grown *in vacuo* by a modification of the Bridgman method which produced a proportion of about 30% single crystals, 50% bi- or tricrystals, and the remainder very coarse polycrystals with a mean grain diameter of 0.5–1.0 cm.

INTERNAL OXIDATION

The specimens, supported four at a time in a refractory holder, were placed in a furnace tube, and held at

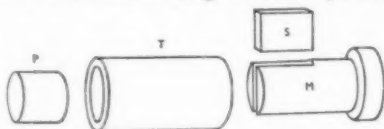


Fig. 1.—Graphite mould for growing single crystals.

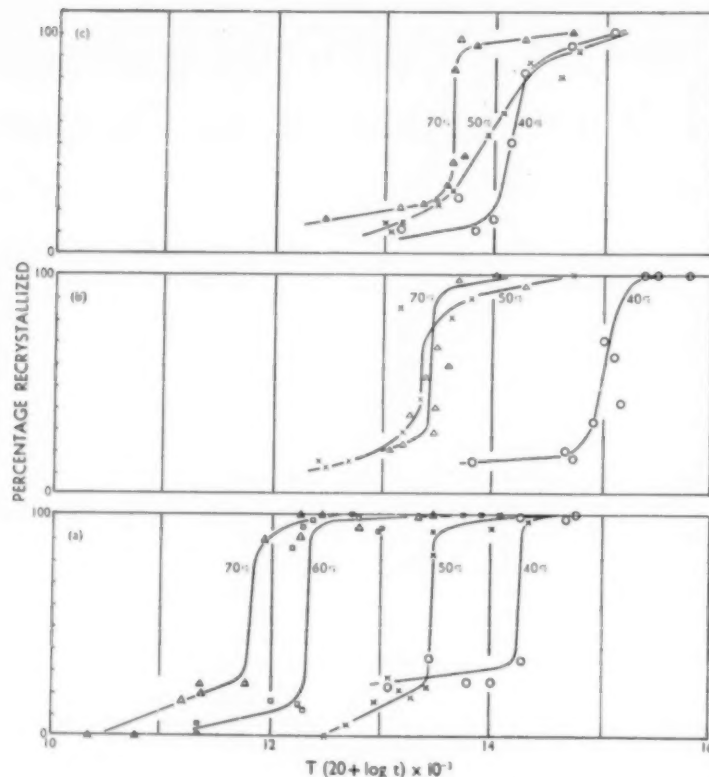


Fig. 2.—The recrystallization of annealed materials: (a) unalloyed copper; (b) Si₁; (c) Si₂.

temperature for half an hour, with an oxidizing atmosphere in the tube. This produced a copper oxide film on the surface of the specimens, and the main part of the heat treatment was subsequently carried out in a neutral atmosphere, when the surface oxide film became the source of oxygen for the complete internal oxidation of the specimen. The neutral atmosphere was produced by passing oxygen-free nitrogen through the furnace.

Before any tests could be performed, it was necessary to determine the rate of internal oxidation of the prepared alloys, over a range of temperatures. Thus suitable oxidation temperatures were selected to give a fully oxidized cross-section in a reasonable time.

Recrystallization Experiments

Previous workers (e.g.^{11,5}) have followed the isothermal recrystallization of deformed specimens over a range of temperatures, and then plotted log. half-softening time against the reciprocal of the absolute temperature to obtain the activation energy. This method requires a relatively large number of specimens which, in the case of the present investigation, would be most time-consuming to prepare. Since each specimen is grown from the melt, and then internally oxidized (which may in itself be a long process), a method due to Larson and Salinas¹² has been employed. The use of their concept reduces the number of tests required to compute recrystallization behaviour.

The hardness (or fraction recrystallized) during recrystallization is plotted as a function of the parameter

$$T(20 + \log t)$$

where T = temperature in °K.

t = time in hours

All the points fall on single "master curves" within the limits attributable to experimental deviations. Larson and Salmas show that, for a constant degree of reaction,

$$T(20 + \log t) = \frac{Q}{2.3 R}$$

where Q = activation energy
 R = gas constant

The authors observe that the scatter of points on the parameter curves is relatively insensitive to changes in the numerical constant, which they chose as 20. Thus a "master curve," in effect, portrays a master plot of a material property (e.g. recrystallization, hardness, etc.), as a function of activation energy. This energy will thus be changing throughout the reaction. The activation energy required (denoted Q_R) has been calculated from the intercept corresponding to 50% recrystallization.

In view of the empirical nature of the Larson and Salmas equation, the calculated Q_R values presented below should only be used as an approximate means of comparing the behaviour of the various types of specimen investigated, and not accepted as absolute values. A determination of absolute activation energies has not been undertaken for the reason stated above, and the use of the Larson and Salmas technique in this exploratory work has provided a simple comparison of recrystallization characteristics.

EXPERIMENTAL TECHNIQUE

Each specimen was abraded with Grade I emery paper until its faces were parallel, when checked with a micrometer, to within 0.0005 in. The specimens were deformed by rolling in a mill, the rolls of which were very highly polished, the material passing between the rolls at a speed of about 0.5 in./sec., and reductions of 0.005 in. per pass were not exceeded. There was thus

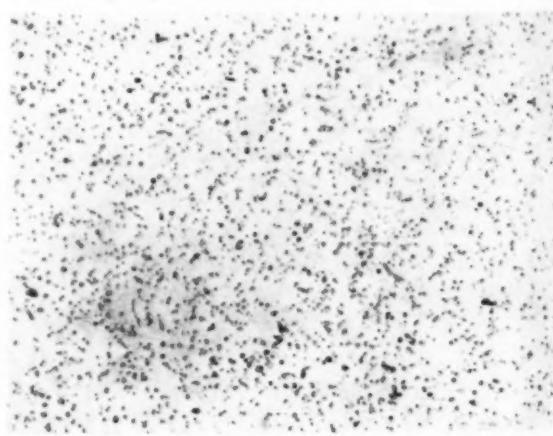


Fig. 3.—Alloy Si₂, internally oxidized at 1,000° C. Unetched. $\times 500$

little danger of the specimens heating up during the deformation process. The strains quoted below were calculated from the expression :

$$\frac{h_i - h_f}{h_i} \times 100\%$$

where h_i = initial thickness
 h_f = final thickness

In order that the strain might be approximately constant across the thickness of the specimens, a minimum reduction of 40% was used. The maximum reduction of 70% was limited by the initial specimen size, and by the necessity to avoid an anvil effect on the hardness testing machine with a load of 1 kg.

The rolled specimens were cut into a number of pieces of approximately equal size ($\frac{1}{4}$ in. \times $\frac{1}{2}$ in.). A miniature hacksaw was used for the purpose, care being taken not to bend or heat the specimen; the burred edges were smoothed with a file. The specimens were attached to a length of thin copper wire and immersed in a salt bath for the requisite time, and then removed and quenched in water. The time taken for the specimen to reach the bath temperature was estimated to be 2-3 seconds; temperature control was effected by means of a Tem-Con electronic controller, and was measured by means of a platinum ν platinum-13% rhodium thermocouple connected to a self-compensating, direct reading potentiometer. This could be read to within $\pm \frac{1}{2}^\circ$ C.

The quenched specimens were abraded with 4/0 emery and their Vickers diamond pyramid hardness number determined, using a load of 1 kg. At least six measurements were made on each specimen, and their mean employed in the graphs. Although the recrystallization of the specimens was observed microscopically, in the experiments described below, the progress of the recrystallization was followed by hardness measurements of this kind. This technique has also been employed by other workers,^{5, 11} the relation between hardness and degree of recrystallization being first established.

TABLE I

	Q_R (k. cal./mol.) after Cold Rolling Reduction of			
	40%	50%	60%	70%
Annealed Materials:				
Unalloyed copper crystals ..	65.4	61.8	56.7	54.2
Si ₁	68.9	61.7	—	61.4
Si ₂	65.0	63.9	—	62.6
Fine polycrystals (0.036 cm.)	55.8	55.4	53.6	52.4
Coarse polycrystals (0.26 cm.)	59.4	59.2	56.1	55.2
Internally Oxidized Materials:				
Si ₁ oxidized at 900° C. ..	61.5	59.8	—	47.5
Si ₁ oxidized at 1,000° C. ..	59.7	50.0	—	46.9
Si ₂ oxidized at 1,000° C. ..	50.9	47.7	—	45.5
Si ₂ oxidized at 1,028° C. ..	—	47	—	42.0

* Value assessed approximately because of lack of specimens.

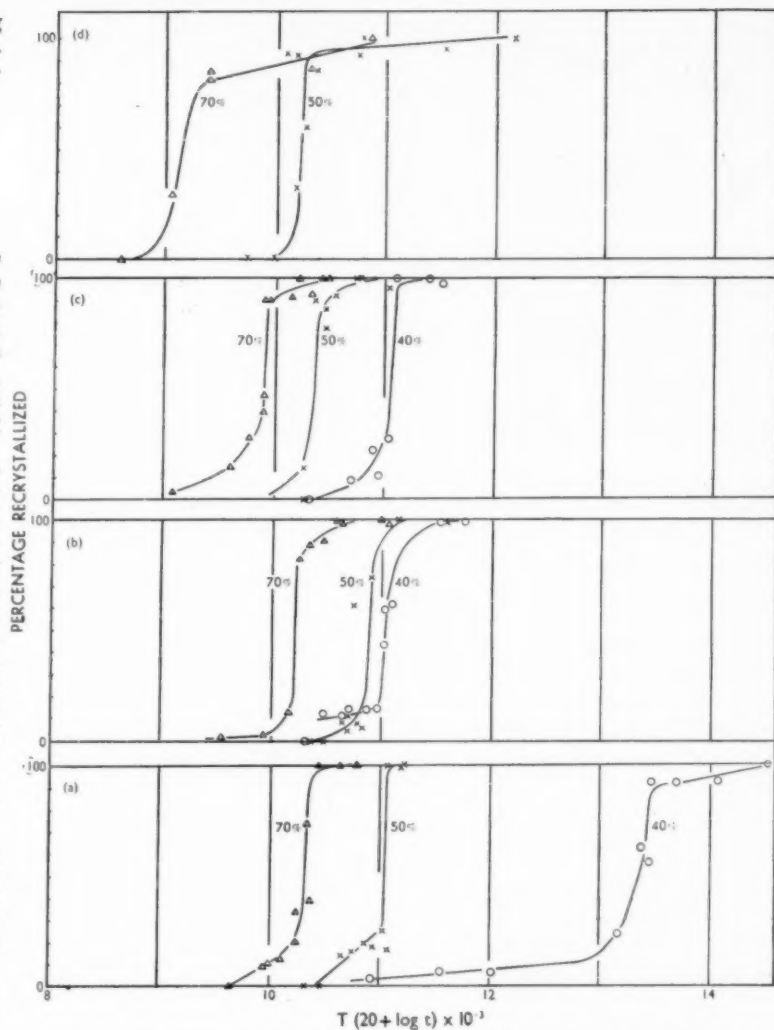


Fig. 4.—The recrystallization of internally oxidized crystals: (a) Si₁, oxidized at 900° C.; (b) Si₁, oxidized at 1,000° C.; (c) Si₂, oxidized at 1,000° C.; (d) Si₂, oxidized at 1,028° C.

EXPERIMENTAL RESULTS

(a) General

The linear relationship between degree of softening and area recrystallized established by Cook and Richards¹¹ and Phillips and Phillips⁵ was confirmed in the case of the alloys used in the present investigation. The technique described by Phillips and Phillips was employed, and a linear relationship obtained for the silica-bearing internally oxidized material, as well as for that with silicon in solid solution.

(b) Annealed Materials

(i) *Unalloyed Copper Crystals.*—The results for various percentage deformations are shown in Fig. 2a, and the values of Q_R in Table I.

(ii) *Alloys Si₁ and Si₂.*—The results are shown in Fig. 2b and c respectively, and the values of Q_R appear in Table I.

(iii) *The Effect of Grain Size.*—Two series of polycrystalline specimens of unalloyed copper were prepared

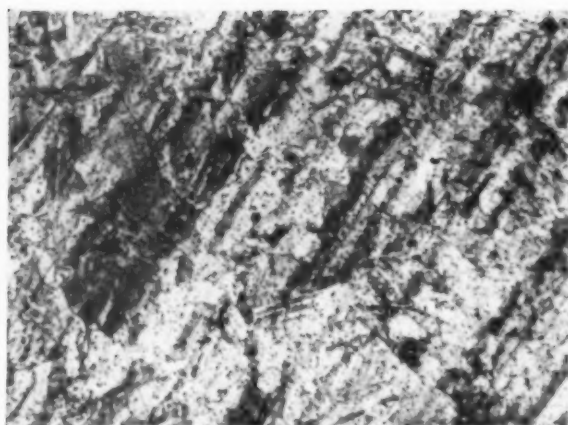


Fig. 5.—Alloy Si_2 (internally oxidized at 1,000° C.), after 50% deformation and recrystallization at 250° C. Etched ferric chloride. $\times 500$

by annealing cold-rolled samples at 410° C and 840° C. for 1 hour. The resulting mean grain diameter was estimated to be 0.036 cm. and 0.26 cm., respectively. The values of Q_R are shown in Table I.

(c) Internally Oxidized Materials

The unetched microstructure of an internally oxidized crystal of alloy Si_2 appears in Fig. 3.

(i) Alloy Si_1 , Oxidized at 900° C.—The results are shown in Fig. 4a, and the values of Q_R in Table I.

(ii) Alloy Si_1 , Oxidized at 1,000° C.—The results are shown in Fig. 4b, and the values of Q_R in Table I.

(iii) Alloy Si_2 , Oxidized 1,000° C.—The results are shown in Fig. 4c, and the values of Q_R in Table I. A fully recrystallized specimen, annealed at 250° C. after 50% deformation appears in Fig. 5.

(iv) Alloy Si_2 , Oxidized at 1,028° C.—The results are shown in Fig. 4d, and the values of Q_R in Table I.

Particle Size Analysis

An analysis of the size of the silica particles was made by a technique described elsewhere,⁷ and cumulative curves were constructed from each histogram. By replotting these cumulative curves on logarithmic-probability graph paper, the diameter (d_s) of the particle having the average surface area may be calculated.¹³ The results are given in Table II.

Discussion of Results

UNALLOYED COPPER CRYSTALS

The observed decrease in Q_R with increasing deformation agrees with the generally accepted concepts of recrystallization behaviour.¹⁴ Metals have been shown to consist after plastic deformation of fine sub-grains,^{15, 16} and the driving force for recrystallization is the strain energy in the sub-grain boundaries^{19, 20, 21}. The observed nucleation frequency will increase with strain, since there will be more distorted regions and local disorientations.

CRYSTALS WITH SILICON IN SOLID SOLUTION

The effect of silicon in raising Q_R has been noted by other workers on the effect of solute atoms on recrystallization (e.g.^{5, 20, 21}). Since recovery may be regarded as

TABLE II

Alloy	Internal Oxidation Temperature (° C.)	d_s (micron)
Si_1	900	0.054
Si_1	1,000	0.066
Si_1	1,000	0.7
Si_2	1,028	0.5

involving the migration of dislocations to positions of greater stability, it then seems probable that many second components in solid solution will impede this migration by "Cottrell-locking."²² If the dislocations can move only as rapidly as foreign atoms diffuse with them, annealing will be slowed down at the recovery stage, which may be before recrystallization has started.

Soluble impurities may tend to segregate at the grain (or sub-grain) boundaries, and thus stabilize them by decreasing their surface energy. Here again, the rate-controlling process in boundary migration will be the rate of diffusion of the solute atoms^{23, 24}.

EFFECT OF GRAIN BOUNDARIES AND DISPERSED SILICA PARTICLES

A lowering of Q_R was observed when either grain boundaries or silica particles were present. The fall in Q_R was greater the finer the grain size, or the higher the silica content, of the specimens. Some reference is made to this effect by other workers. Perryman⁶ refers to unpublished work that insoluble intermetallic compounds in aluminium-magnesium alloys increase the nucleation rate, regions of high lattice curvature being more likely sites for nucleation. Phillips and Phillips⁵ investigated copper containing tellurium, which was probably precipitated during prior annealing, and the presence of this element was observed to accelerate recrystallization. Clarebrough²⁵ investigated the deformation and recrystallization of two-phase silver-magnesium alloys, and concluded that when the proportion of β -phase is small, an additional deformation of the α -phase occurs round the hard β -particles, illustrating the effect by plotting the deformation per unit volume of α -phase against volume fraction of β . This effect could clearly lower the observed Q_R for crystals containing a hard dispersed phase.

Another relevant observation has been made on the creep²⁶ and elevated temperature tensile²⁷ properties of some aluminium-based alloys. In contrast to their low-temperature properties, the stress-strain curves between 295 and 700° K., of 3, 4 and 5% copper-aluminium alloys containing dispersed $CuAl_2$ particles, did not form an homologous family. This was because those containing coarser dispersions recovered at a slower rate than those with the finer dispersions. Consequently, at about 500° K., those with coarser dispersions were stronger than those with finer dispersions, but at higher temperatures, where recovery is essentially complete, those containing finer dispersions again exhibited a somewhat superior flow stress to those with coarser dispersions, in harmony with the trends at low temperatures.

The particle-matrix interface in internally oxidized single crystals (like grain boundaries in the unoxidized polycrystals) are regions where, on plastic deformation, there is likely to be high lattice curvature. Thus the dispersed particles may be regarded as producing an effect on recrystallization behaviour comparable to that of an array of grain boundaries.

TABLE III

Specimen	r (micron)	f	$4r/3f$ (cm.)	Q_R (70%) (k.cal./mol)
Unoxidized single crystals	0	0	0	54.2
Si_2 oxidized at 900° C.	0.027	0.00425	0.00085	47.5
Si_2 oxidized at 1,000° C.	0.033	0.00425	0.00104	46.9
Si_2 oxidized at 1,000° C.	0.35	0.0208	0.00224	45.5
Si_2 oxidized at 1,028° C.	0.25	0.0208	0.0016	42

It can be shown that, if n is the number of particles (of mean radius r) per unit volume, the mean particle spacing is

$$\frac{1}{n r^3}$$

But, if f is the volume fraction of oxide

$$n = \frac{f}{\frac{4}{3} \pi r^3}$$

$$\text{so, particle spacing} = \frac{4r}{3f}$$

This expression is identical with a formula reported by C. S. Smith²⁸ from the work of Zener, concerning the effect of a dispersed phase on grain growth in polycrystals.

A particle of low dihedral angle will tend to become attached to the grain boundary, and tend to anchor it locally. Zener derived the following relationship between particle radius and the radius of curvature of the grain for the idealized case of spherical particles of equal size and uniform distribution:

$$G = \frac{4r}{3f}$$

where G = net radius of curvature of grain

f = volume fraction of inclusions

r = radius of inclusion particles

Thus, this expression may be used as an approximate measure of an "equivalent grain size" in internally oxidized single crystals, if G is assumed equal to an "equivalent grain radius" (not radius of curvature).

In alloy Si_2 , the volume fraction of silica, $f = 0.00425$; and in alloy Si_2 , $f = 0.0208$. The values of $4r/3f$ for the oxidized crystals investigated appear in Table III.

The $4r/3f$ values may be compared with the value of Q_R at 70% deformation (at which strain the Q_R - strain curves are approximately parallel). Apart from Si_2 oxidized at 1,028° C., Q_R decreases with increasing "equivalent grain size," although, as $4r/3f$ approaches infinity, Q_R must return to the value obtained with unoxidized polycrystals. This effect is reflected in the rise in Q_R obtained with increasing grain-size in the annealed polycrystalline specimens, and is summarized in Fig. 6.

Further experimental work is desirable on the phenomena described. A microbeam X-ray diffraction technique should be employed to examine and compare the sub-grain structures produced in all these materials after plastic deformation, and the effect of the finer dispersoids produced on internally oxidizing copper-aluminum alloys should also be investigated. The work discussed may well have bearing, not only on the heat treatment and annealing of alloys containing hard dispersed particles, but also on their general high-temperature and creep properties.

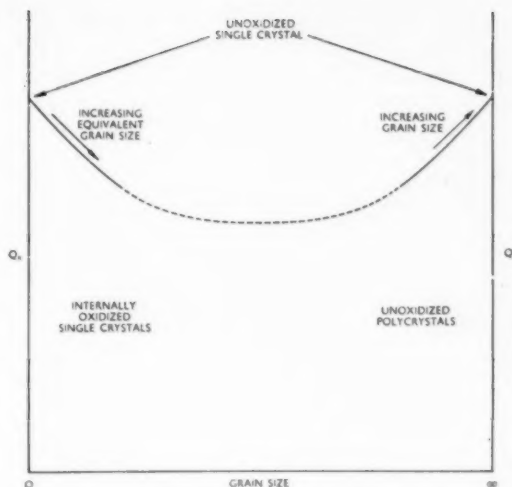


Fig. 6.—Relationship between "grain size" and the activation energy required for 50% recrystallization.

Acknowledgments

The work described in this paper was carried out during the tenure of an Imperial Chemical Industries Fellowship in the University of Cambridge Department of Metallurgy. The author is indebted to Professor G. W. Austin, O.B.E., for the laboratory facilities he made available, and for his continued interest in the work, and also to Mr. G. C. Smith for many valuable discussions.

REFERENCES

- Burke, J. E. and Turnbull, D. Ch. in "Progress in Metal Physics" (3), Pergamon Press, London, 1952.
- Crussard, C. *Met. Corr. Ind.*, 1953, 28.
- Deighton, M. *Bull. Inst. Metals*, 1956, 3, 93.
- Stanley, J. K. *Trans. Amer. Inst. Min. (metall.) Engrs.*, 1945, 162, 116.
- Phillips, V. A. and Phillips, A. J. *Inst. Metals*, 1952, 81, 185.
- Perryman, E. C. W. *Trans. Amer. Min. (metall.) Engrs.*, 1955, 203, 369.
- Martin, J. W. and Smith, G. C. J. *Inst. Metals*, 1955, 83, 153.
- Martin, J. W. and Smith, G. C. *ibid.*, 417.
- Smith, G. C. and Dewhurst, D. W. *Australian Inst. Met.*, Melbourne Branch, *Trans. Met. Div. Drepint*, (1950).
- Gregory, E. and Smith, G. C. *J. Inst. Metals*, 1956, 85, 81.
- Cook, M. and Richards, T. L. *J. Inst. Metals*, 1947, 73, 1.
- Larson, F. R. and Salmas, J. *Trans. Amer. Soc. Metals*, 1954, 46, 1377.
- Dallavalle, J. M. "Micromeritics," Pitman, London, 1948.
- Anderson, W. A. and Mehl, R. F. *Trans. Amer. Inst. Min. (metall.) Engrs.*, 1945, 161, 140.
- Beck, P. A. *Advances in Physics*, 1954, 3, 245.
- Gay, P. and Kelly, A. *Acta Cryst.*, 1953, 6, 165.
- Perryman, E. C. W. *J. Metals*, 1955, 9, 1052.
- Averbach, B. L., Cohen, M., Allen, S., Comerford, M. F., and Houska, C., M.I.T. (U.S. Atomic Energy Commission), NYO-7075, June 1955.
- Averbach, B. L., Bever, M. B., Comerford, M. F., and Leach, J. S. *Acta Met.*, 1956, 4, 477.
- Kawashima, N. and Nakamura, Y. *Nippon Kinzoku Gakkai-Si*, 1952, 16 (9), 495.
- Seymour, W. E. and Harker, D. *J. Metals*, 1950, 188, 1091.
- Cottrell, A. H. "Report of Conference on Strength of Solids," London, Phys. Soc., 1949, 30.
- Decker, B. F. and Harker, D. *Trans. Amer. Inst. Min. (metall.) Engrs.*, 1950, 188, 887.
- Burke, J. E. *ibid.*, 1949, 180, 73.
- Clarebrough, L. M. *Australian J. of Scient. Res.*, 1950, 3, 72.
- Giedt, W. H., Sherby, O. D. and Dorn, J. E. *Trans. Amer. Soc. Mech. Engrs.*, 1955, 77, 57.
- Starr, C. D., Shaw, R. B., and Dorn, J. E. *Trans. Amer. Soc. Metals*, 1954, 46, 1075.
- Smith, C. S. *Trans. Amer. Inst. Min. (metall.) Engrs.*, 1948, 175, 15.

THE Middlesbrough Branch Office of Honeywell-Brown, Ltd., has moved to larger premises. All enquiries concerning industrial instrumentation, heating and air conditioning controls, and precision switches, should be addressed to: Honeywell-Brown, Ltd., 52-60, Fletcher Street, Middlesbrough (Telephone: Middlesbrough 44221/3. Telegrams: Minnreg, Middlesbrough.)

New Heavy Chromium Deposition Plant

Fescol Provide Increased Facilities

NEW plant for the electro-chemical deposition of chromium, which can accommodate components up to 15 ft. long, 5 ft. diameter, and weighing up to 6 tons, has just been completed at the Port Glasgow works of Fescol, Ltd.

The Company operate chromium deposition plants at Port Glasgow, and also in London, Huddersfield and Brownhills (Staffs.), but the demand from customers was increasing for the treatment of articles which were larger than could be handled comfortably with these existing facilities. The new plant, designed specifically to meet this demand, was installed in an existing factory to obtain maximum benefits from the available ancillary services, and also for ease of control. It was considered also that the installation of the plant in an existing works could be completed far more quickly and at a lower cost than would the building of a new and additional factory, and in fact was completed within less than 12 months from the date of the decision to proceed.

As the London plant is capable of handling nickel deposition on articles of up to 6 tons, it was necessary that the new chromium plant should have a similar capacity, as the Company frequently carry out nickel deposition to build up heavily worn components before the final chromium is deposited.

The treatment of articles up to 15 ft. long and weighing 6 tons would normally present great difficulties in an existing factory having a height to eaves of 20 ft., as the

normal types of hoist take up an appreciable part of the head-room. While the initial discussions were taking place, a Scandinavian low head-room hoist, the Munch, was introduced into the U.K. by Taylor Stoker Co., Ltd. After investigation it was decided to install a 6 ton version of this hoist at Port Glasgow, as it required a space only 2 ft. from the underside of the beam to the hook, when fully withdrawn, leaving 17 ft. between hook and floor. Two further advantages of the hoist were a micro-speed lift for inching and low-voltage push-button operation. The runway over the five deposition and preparatory tanks has been designed to carry a load of 10 tons, so that no structural alterations will be necessary if the weight-lifting capacity should be increased at a later date.

The vats are housed in an asphalt-lined pit excavated from shale and rock, with the tops on a level with the factory floor. Space has been left between tanks for inspection and repair, access for the operators being by means of a gallery along the length of the pit. The depth of excavation that was necessary brings the effluent from the vats below the level of the existing drains, so that a sump had to be formed in the gully and acid-resistant pumps installed to transfer the effluent to the main drainage system. A specially-designed system of cooling is used to ensure close control of the temperature of the deposition vats; it enables the chosen temperature to be maintained to $\pm 1^\circ \text{F}$.

The current supplied to the new plant is over three times that provided to any one chromium deposition vat in the Company's London works, the electrical supply being through Westinghouse rectifiers and reverse switches. Two groups of the oil-immersed rectifiers, with stepless regulators, are placed close to the vats to ensure a minimum voltage drop in the conductors.



The component shown being treated in this view of the plant is a film drying drum used in the production of manganese sulphate monohydrate.

Compoflex to Market Rigid Tubing

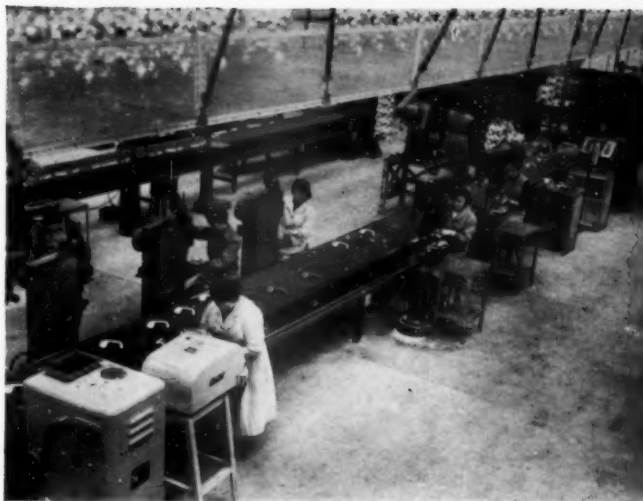
COMPOFLEX Co., LTD., have extended their flexible advisory and manufacturing facilities to include certain forms of rigid tubing by the acquisition of the entire share capitals of Rollo Hardy & Co., Ltd., and Tube Making Machines, Ltd.

During the past ten years, Compoflex have built up what is claimed to be the only comprehensive flexible service in the world. At the advisory centres in London and Oldham, potential customers can obtain unbiased advice on the most efficient flexible to use for any given situation, as Compoflex are the only manufacturers producing plastics, rubber, metallic and composite hoses within the one organisation. The extension of this service to include rigid tubing is claimed to be a logical development.

Rollo Hardy & Co., Ltd., which was formed in 1947, produce rigid welded, and welded and drawn, stainless steel tubes; Tube Making Machines, Ltd., also established in 1947, manufacture mild steel tubing and also, as their name suggests, design and produce tube-making machinery and equipment.

Line Production of Pressure Die Castings

New Production Techniques at Wolverhampton



Trimming and machining operations on one of the belt conveyors. A part of the storage conveyor can be seen overhead.

IN common with many other firms, the Wolverhampton Die Casting Co., Ltd., has for some time been concerned with the need to offset increasing costs by greater efficiency of operation. Considerable success in this direction has been, and can further be, achieved with existing facilities in the way of buildings, plant and layout, but it was decided to carry out a complete survey of all aspects of pressure die casting production without consideration of such physical limitations.

Pressure die casting has often been quoted as "the shortest distance between raw material and finished product." This is undoubtedly true, but it became apparent that the adoption of modern flowline production techniques, in a specialised form, could further reduce this distance by a considerable margin. It was obvious that the use of flowline techniques in an essentially jobbing business posed a variety of complex problems, but full consideration showed that none of them was insuperable.

Most desirable of all the advantages associated with such methods was the near-abolition of manual handling. This, in addition to its undeniable cost reductions, is of particular importance in pressure die casting, where a considerable proportion of the output is destined for subsequent polishing and chrome plating. Pressure die casting in itself is capable of producing exceptionally fine finishes on castings, much of which can, unfortunately, be lost by subsequent damage in handling.

Early in 1954, therefore, the engineering and development staffs of the company were instructed to devote their energies to the production of detailed plans for the adaption of flowline methods to the production of die castings. The board of the company had for many years maintained close contact with a number of American die casting firms, and as planning proceeded it was thought desirable to check conclusions against actual practice in the United States. A visit was therefore made by Mr. F. C. Stockham, Works and Development Engineer, and Mr. J. A. Brittle, Factory Planning Engineer, to a large number of firms, and it was a matter of pride to the company that full confirmation of all their planning was obtained in that country.

Preliminary Planning

As a preliminary to the detailed planning prior to the visit to the United States, a survey was carried out of existing methods of production, including an examination of every point where avoidable cost might be incurred, or the quality of the casting might suffer. It should be emphasised that present methods are considered as efficient as possible under the batch handling method common throughout the industry, and the majority of jobs, mainly those where quantities do not warrant line production methods, will still continue to be dealt with in this way. A brief summary of this survey is set out below.

Raw material, in the form of Mazak ingot, was melted in a number of service pots in the foundry, whence it was ladled by hand to the individual die casting machine holding furnaces. Castings were produced on operator-controlled machines, the operator being responsible for the timing of casting sequences. The castings, attached to their sprues and runners, were placed upon a bench, and when sufficiently cool, were broken off the runners and loaded into stillages. The scrap sprues and runners were removed by hand to a central re-melting shop for conversion into ingot.

The stillages were then transported by truck to the various trimming departments for their finishing operations, such as pressing, drilling, tapping, etc. On each of these operations, which might well number up to ten, the casting had to be removed from, and replaced in the stillage, for transportation to the next operation. It was general practice to cast the full quantity required regardless of the speed at which castings could be finished; consequently, many of the castings remained in storage for some weeks before final finishing.

Quite apart from the obvious points at which cost savings could be made, these methods resulted in two particular forms of imperfection in the casting: (1) faults attributable to the operation of the die casting machine; (2) damage during handling, in the form of indentations on the face of the castings.

The incidence of casting faults was varied. Whilst one operator could produce nearly 100% good castings,



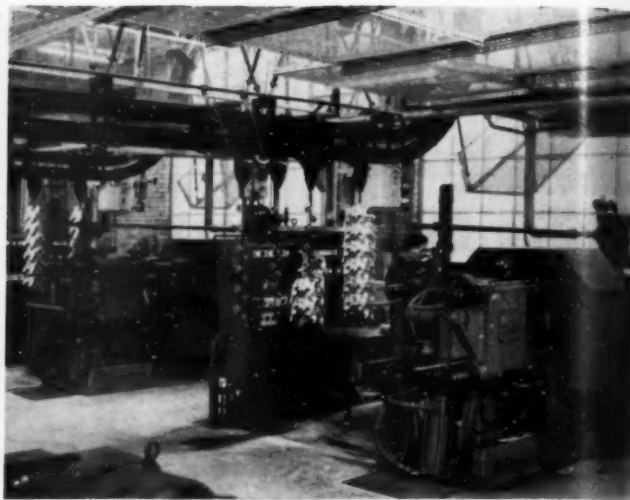
Metal holding furnaces with resistance heated interconnecting launders (covers removed).

another operator could have as much as 5% or 10% scrap from the same die. Usually, this fault was related to the number of shots per hour attained by operators, which affected temperatures and other working conditions. It was realised that the only method of overcoming this difficulty was to have the die casting process controlled automatically.

Most damage to castings was caused by mis-handling of a type which was extremely difficult to control, and much of which was not evident until the casting had been polished. Many of the operations were of a rapid nature, and the natural tendency was for operators to handle castings carelessly. The only solution was felt to be to present each casting separately to an operator at a controlled rate through all phases of production.

Basic Planning

On consideration of all the points which emerged from the investigation, the following basic plan was put forward. The plant houses a number of die casting machines, each with its own finishing line for subsequent operations. Each of the finishing lines is capable of dealing, not, of course, with one product only, but with a particular type or class of product. On the completion of orders for a particular job the tooling on the line is capable of rapid change to meet the operations required on the next production run. In order to achieve maximum utilisation of capital equipment, it has always been the policy of the company to operate the expensive die casting machines on a night and day basis. On the other hand, the bulk of the finishing operations can be efficiently and economically performed by female labour, which, of course, precludes night time operation. Consequently, the conveyor linking the die casting machines with the finishing lines must be capable of storing a complete night's work in the "as-cast" condition and, correspondingly, finishing lines must be capable of working at twice the speed of the casting



Two Schultz die casting machines with electronic control cabinets. The initial loading position for the storage conveyor is also seen.

machines in order to dispose, during day time, of a night and day's castings. During storage the castings are hung on the conveyor complete with sprues and runners, until the first trimming operation which separates them. Thereafter, the castings are passed from operation to operation, singly upon a belt conveyor.

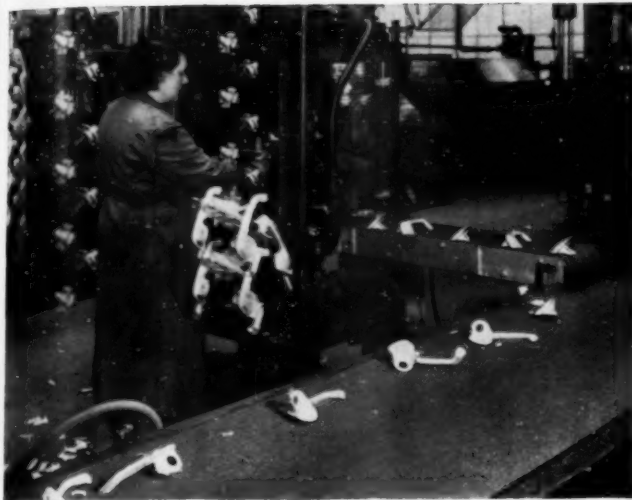
Detailed Planning

Metal Melting

During the early investigations much thought was given to the method of feeding metal to the die casting machine holding furnaces. Various schemes were considered, chief amongst which was the provision of one main melting furnace from which molten metal could be drawn off into a large ladle. This ladle, carried on a mono-rail, could be so arranged that any of the holding furnaces could be replenished as required. It was finally decided to employ a method of metal feeding which had been used with some success in the United States, and had been seen in operation during the visit there. The system, known as the Birlec-Tama, is manufactured in Great Britain by Birlec, Ltd., and makes use of low frequency electrical induction furnaces. In the plant, as equipped at the moment, two main melting furnaces of 60 kW. capacity are employed, one at each end of the line of die casting machines. Each machine is equipped with a 20 kW. holding furnace, and the whole system is inter-connected by a series of resistance heated launders, along which the molten metal finds its own level throughout. Labour costs are thus restricted to the feeding of the main melting furnaces only. Metal losses during melting have been found to be as low as 0.3-0.4%, and the whole system is particularly cool and clean in use.

Die Casting Machines

The die casting machines are Schultz Model GJ 21 in. units manufactured by The Vincent Engineering Co., Ltd., of Glasgow. An earlier model of this machine is standard throughout the company's main foundry, but these latest machines are equipped with electronic control of the casting cycle, a highly desirable feature in the elimination of scrap castings and the maintenance of optimum production rates.



Castings passing from the first operation, which is separation of the castings from the sprue, on to the trimming conveyor belt.

Conveyors

There are three types of conveyor—storage, trimming, and metal reclaiming.

Storage Conveyors.—Probably the most important item of equipment is the conveyor linking the die casting machines with the trimming lines. That finally chosen was a new form of indexing conveyor, the Flowmaster, manufactured by Fisher & Ludlow, Ltd. An individual conveyor is attached to each machine with a length of 389 ft., which is accommodated in several loops above the trimming lines. Close co-operation was maintained with Fisher & Ludlow's design department, and experiments were carried out to ascertain the best type of carrier on which to suspend the sprays of castings, complete with runners and sprues, from the conveyor. The actual run of the conveyor, with rises and falls, was given much thought to avoid interference with the remainder of the plant.

The conveyor is equipped with handing "trees," steel rods with a number of staggered branches, on to which each complete spray of castings is hung in such a way that castings cannot touch each other. As soon as the casting machine operator has loaded a "tree" this moves away into close packed storage in the roof space and an empty "tree" takes its place. The first operator on the trimming line can call carriers either from the bulk store of castings from the night shift, or direct from the casting machine, according to the time of day. It will be noted that the storage of the night shift's work from the casting machine not only allows female labour to be used on the trimming lines, but also forms buffer stock against minor die breakdowns or variations in production rates.

Trimming and Metal Reclaiming Conveyors.—Once a spray of castings has been removed from the Flowmaster conveyor for the first trimming operation, its subsequent progress is along a fabric "flowline" belt conveyor also manufactured by Fisher & Ludlow. This first operation is almost invariably the pressing of the actual casting from its sprue, runners and vents. The casting itself is dropped on to the belt conveyor, along which it passes through subsequent operations, and the sprues, etc., pass



Method of transporting scrap from the first trimming operation to the subway.

down a short conveyor on to the metal reclaiming conveyor. This is housed in a large subway, 6 ft. wide \times 7 ft. high, which runs the entire width of the shop, with hatches at the head of each trimming line. This subway also carried the various services to the die casting machine in the way of water, compressed air, etc.

The provision of this metal reclaim conveyor was a considerable problem. A number of different types were inspected and found to suffer various disadvantages. The normal wire mesh belt was found to wear quickly and was rather easily distorted by the type of scrap with which it was required to deal. The slat type of conveyor, favoured by many plants in America, was prone to jamming through portions of scrap working their way through the slats. Eventually Fisher & Ludlow devised a conveyor, some 137 ft. long, and so constructed as to elevate from the subway to floor level at one end, which it was felt would overcome all these disadvantages. This conveyor deposits the metal for reclaiming in the vicinity of the main remelting house.

Trimming Lines

The prime object in the planning of the trimming lines was the necessity of ensuring that each was adaptable to as large a range of castings as possible. In full production, the average length of run of components suitable for this form of production is little more than one week, at the end of which time the die must be changed and, consequently, all the tools and many of the operations on the trimming lines. It is this fact that raises a host of problems not normally associated with line production methods where, once set, a line may be expected to run for perhaps many months.

The problem has been met by the most careful selection of machinery for each line, training of operators to a variety of tasks, and meticulous attention to the planning of the production programme. In this latter con-

nection, investigations are proceeding into the possibility of using the Powers-Samas punched card system, at present used for the company's payroll and costing system, for production planning. It is possible to classify every die casting job by the number and type of operations to be subsequently performed upon it, and since each line has been laid out in regard to length, machinery, number of operators, etc., common to a group or range of jobs, the possible assistance which might be gained from this system is readily apparent.

A further practical contribution to this problem has been the provision of a die casting machine without its attendant conveyors and production lines. This machine has attached to it a number of finishing machines—presses, drillers, tappers, etc.—capable of dealing with certain stock jobs of a fairly continuous nature, but provided with only one or two operators who work these finishing machines progressively. Whilst production is proceeding normally on the flowlines the bigger of the castings from this machine are diverted to the normal finishing departments of the main works. In case of stoppage on a flowline, however, the flowline

operators are diverted to this spare machine, and standing time is thereby saved.

Conclusion

The main advantages of this method of production may be summarised as follows:—

(1) The whole production of each job, from raw material to finished component ready for despatch, is under immediate supervision.

(2) The efficiency of tooling and technique for each and every operation is continuously highlighted, since subsequent operations are dependent upon it.

(3) Castings reach final inspection with the minimum of delay, and faults can therefore be corrected as they occur.

(4) By presenting each casting singly, and at a controlled rate, the possibility of damage is reduced to negligible proportions, even at a rate of flow of 500 to 600 per hour.

(5) Labour cost for transport of castings between operations is virtually nil.

Meeting Diary

2nd April

Institute of Metals, Oxford Local Section. "Fatigue," by Dr. N. THOMPSON, preceded by the Annual General Meeting. Cadena Cafe, Cornmarket Street, Oxford. 7 p.m.

3rd April

Institute of Welding, Manchester and District Branch. Annual General Meeting, and Film by BABCOCK & WILCOX, LTD. (with commentary). Reynolds Hall, College of Technology, Manchester. 7.15 p.m.

Society of Chemical Industry, Corrosion Group. "The Protection of Structural Steel against Corrosion," by J. C. HUDSON. (Joint Meeting with the South Wales Section). The Technical College, Newport, Mon. 7 p.m.

4th April

Institute of Metals, London Local Section. "Recent Developments in Electron Microscopy," by Dr. J. NUTTING, preceded by the Annual General Meeting at 6 p.m. 17, Belgrave Square, London, S.W.1. 6.30 p.m.

Leeds Metallurgical Society. "Fatigue in Metals," by P. J. E. FORSYTH. Large Chemistry Lecture Theatre, The University, Leeds, 2. 7.15 p.m.

8th April

Institute of Production Engineers, Halifax Graduate Section. "Production of Machine Tool Castings," by G. W. NICHOLLS. Huddersfield Technical College. 7.30 p.m.

Society of Chemical Industry, Corrosion Group. Spring Lecture. "Corrosion Researches of Professor Piontelli and his associates at Milan," by R. PIONTELLI. Society of Chemical Industry, 14, Belgrave Square, London, S.W.1. 6.30 p.m.

9th April

East Midlands Metallurgical Society. "Nickel Base Alloys for High Temperature Service," by A. FRANKLIN. Nottingham and District Technical College. 7.30 p.m.

Society of Instrument Technology, Manchester Section. "The Science and Art of Instrumentation," by J. K. BURKITT. Manchester College of Technology. 7.30 p.m.

11th April

Incorporated Plant Engineers, Glasgow Branch. "Applications of Photography in Industry," by A. HORDER. Scottish Building Centre, 425/427, Sauchiehall Street, Glasgow. 7.15 p.m.

Incorporated Plant Engineers, Merseyside and North Wales Branch. "Engineering in the making of Refractories," by E. SNODGRASS. The Exchange Hotel, Liverpool. 7.15 p.m.

Institute of British Foundrymen, Beds./Herts. Section. Films: "New Foundry Horizons" and "Plans for a New Foundry," preceded by Annual General Meeting. W. H. Allen, Sons & Co., Ltd., Bedford. 7.30 p.m.

Liverpool Metallurgical Society. "Vacuum Techniques in Metallurgy," by M. HARPER, and Annual General Meeting. Liverpool Engineering Society, The Temple, Dale Street, Liverpool. 7 p.m.

Society of Instrument Technology, Tees-Side Section. "Some Aspects of Quality Control Instrumentation," by G. C. ELTENTON, and F. SUMNER. Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough. 7.30 p.m.

12th April

Institute of Physics, Non-Destructive Testing Group. "Damping Capacity and Fatigue," by Dr. K. M. ENTWHISTLE. 47, Belgrave Square, London, S.W.1. 6.30 p.m.

Institution of Heating and Ventilating Engineers. "Modern Methods of Oil Firing," with film. SHELL-MEX and B.P., LTD. County Offices, Preston. 7 p.m.

North East Coast Institution of Engineers and Ship-builders. "Failure of Welded Steel Structures," by T. W. BUSHILL. Mining Institute, Newcastle-upon-Tyne. 6.15 p.m.

West of Scotland Iron and Steel Institute. Annual General Meeting and "Continuous Casting," by J. R. RIPPON. 39, Elmbank Crescent, Glasgow. 6.45 p.m.

15th April

North East Coast Institution of Engineers & Ship-builders, Tees-Side Branch. "Failure of Welded Steel Structures," by T. W. BUSHILL. Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough. 6 p.m.

16th April

Institute of British Foundrymen, East Anglian Section. "Foundries and Foundry Management," by H. W. KEEBLE, preceded by Annual General Meeting at 7.15 p.m. Lecture Hall, Public Library, Ipswich. 7.30 p.m.

17th April

Institution of Production Engineers, Peterborough Section. "Production of Raw Materials from Rolling Mills," by J. McLAUCHLAN. The White Lion Hotel, Church Street, Peterborough. 7.30 p.m.

Institute of British Foundrymen, London Branch. "Flow of Metals into Moulds," film and discussion, preceded by Annual General Meeting at 7 p.m. Constitutional Club, Northumberland Avenue (south-east from Trafalgar Square), London, W.C.2. 7.30 p.m.

25th April

Incorporated Plant Engineers, Sheffield and District Branch. "Welding Applied to Maintenance," by A. O'DONNELL. Grand Hotel, Sheffield. 7.30 p.m.

Institute of Physics, Midland Branch. "The Strength of Metals," by Dr. A. H. COTTRELL, F.R.S. Regent House, Birmingham. 7 p.m.

29th April-4th May

Institute of Metals. Joint Spring Meeting with Associazione Italiana di Metallurgia, Société Suisse des Constructeurs de Machines, and Association Suisse pour L'Essai des Matériaux. Church House, Westminster.

The Prevention of Accidents in Iron and Steel Works

Bogie Couplings—Straightening Machines—Gas

QUITE apart from the damage to personnel resulting from accidents of one form or another, many of which prove fatal, their influence on output is considerable, and from the human as well as the material point of view, it is of the greatest importance to study ways and means likely to lead to their prevention. In recent years, particularly, a good deal of thought has been given to the prevention of accidents in almost every sphere of industrial activity, as a result of which control in limiting hazards has become more exacting. Unfortunately, as sometimes happens, familiarity breeds contempt, and the precautions recommended to reduce the hazards are disregarded.

The extent to which hazards exist varies in different industries, but proper co-operation between management and employees in adopting means of reducing dangers known to exist would lead to a substantial reduction in the number and seriousness of accidents. In such a complex industry as the iron and steel industry, the Accident Prevention Committee of the British Iron and Steel Federation decided, in July, 1954, that a series of technical investigations should be made into certain hazards associated with particular operations in steel-works and, in consultation with the Factory Department of the Ministry of Labour, a number of sub-committees

were set up to deal with specific problems. Reports of several of these sub-committees, approved by the Accident Prevention Committee, have recently been published, and are discussed in the following notes under the specific problems with which they deal.

THE SAFE COUPLING OF INGOT CASTING CARS AND SCRAP PAN BOGIES

The report on the above subject is presented by a Sub-Committee set up under the Chairmanship of Mr. R. L. WILLOTT (John Summers and Sons, Ltd.), to examine the coupling of special types of rolling stock in iron and steel works, and is concerned with couplings for ingot casting cars and scrap pan bogies. The coupling problem was selected for study because accidents involving casting cars and scrap pan bogies, though not numerous, are often serious when they do occur, perhaps resulting in permanent disablement or loss of life. Investigations were made in a representative number of works, and examples of all types of coupling in use in the country were examined. Different managements and operators were consulted and their opinions have been considered in preparing the report.

The Sub-Committee recommends that all couplings in use on casting cars and scrap bogies should conform to the following principles: (1) the method of operation must not expose the shunter to undue risk of injury; (2) the method of actuation must be the simplest and, if possible, the *only* method available; (3) the coupling must have adequate operating latitude to meet general working conditions; (4) the coupling must have sufficient strength and durability for the specified duty; it must also be adequately protected against hot metal spillage, falling materials and general fouling, as may be appropriate; and (5) the coupling must be easily and efficiently maintainable.

It is emphasised that the shunter should not be required to go between vehicles, and it is to be preferred that it should not be possible for him to operate the coupling from between the vehicles, and that actual coupling elements should never be handled directly by the shunter under any circumstances. It is also recommended that all simple vertical pin couplings should be converted, where practicable, to the bottom entry lever operated type, of which an example is shown in Fig. 1.

The method of actuation of automatic couplings must be designed so that the shunter need not go between vehicles to couple and uncouple; actuation should not involve the use of a special coupling pole. This latter point is emphasised for scrap pan bogies, due to the high frequency of coupling operations in this class of traffic.

THE SAFE OPERATION OF BAR REELING AND STRAIGHTENING MACHINES

The report on the above subject is presented by a Sub-Committee set up under the Chairmanship of Mr.

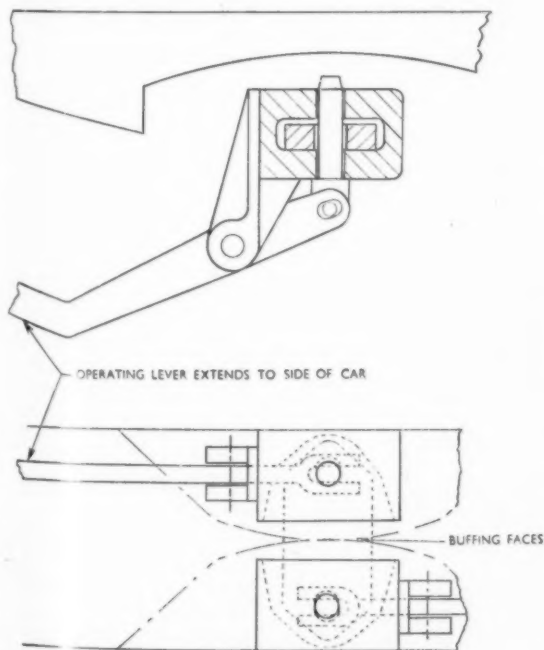


Fig. 1.—Lever operated (bottom entry) vertical pin type coupling for ingot casting cars.

W. W. HICKMAN (Wolverhampton and Birchley Rolling Mills, Ltd.), to investigate accidents occurring at reeling and straightening machines, and to try to find means of preventing them. The results of previous investigations were studied, the manufacturers of reeling and straightening machines were consulted, and examinations were made of the methods of operation and the types of work carried out in various works on different types of machine. Based on the information obtained, conclusions have been reached on the risks to which the operator and others are exposed, and recommendations are made on effective methods of protecting persons from these risks.

The principal hazards connected with ungaurded reeling and straightening machines are: (1) that a person may be struck by the bar as it whirls or whips out of line: this is possible at both entry and delivery ends of the machine; (2) that a person may be caught up or entangled with the bar at any point in its length as it enters or leaves the machine, and (3) that a person may be injured by the ordinary rotating parts of the machine.

The recommendations of the Sub-Committee are carefully detailed, and the following points are stressed. Badly bent bars should be rough straightened by hand or in a gag press prior to machine straightening. A feed table should be provided at the inlet side of all machines on continuous production, so that manual handling of the bars is reduced to a minimum, and inlet guides should be enclosed by a continuous guard for the whole length of the longest bar to be handled. The guard should normally be of the type which allows the bar to be put in the guide from one side. The practice of entering the bar by hand should be eliminated: the hand-operated quadrant is a suitable method of feeding, but, for high production rates, power operated feeds are recommended. All outlet guides should be adequately protected against accidental contact with the rotating bar, and every effort should be made to eliminate manual handling of the bars at the outlet side of the machine. The manufacturers of straightening and reeling machines should supply suitable guards, guides and feed gear as standard equipment on all new machines and should provide an emergency stop switch within easy reach of the operator. All machine adjustments should be made by a trained operator or setter. A regular programme of preventive maintenance should be operated on straightening machines and on guards and guides. The capacity of straightening and reeling machines should be determined for all qualities of steel likely to be rolled in any particular works, and these capacities should not be exceeded. In the final recommendation the Sub-Committee consider it desirable that B.I.S.R.A. should be asked to carry out an experimental investigation into the effect of size and other physical variations in the bars being straightened on the behaviour of those bars as they are passing through the machine. If positive results are forthcoming, it should be possible to determine safety limits of size and other variations for bars to be reeled or straightened.

THE PREVENTION OF GASSING ACCIDENTS IN IRON AND STEEL WORKS

Gassing accidents in iron and steel works have been investigated by a Sub-Committee set up under the Chairmanship of Mr. I. S. SCOTT-MAXWELL (Steel Company of Wales, Ltd.), with a view to the recommendation of means for reducing the risk, because of the relatively high percentage of fatalities encountered. The Sub-

Committee's conclusions and recommendations are given in the first part of the report, while the second part reviews the gassing accidents that occurred in the industry from 1952 to 1954, and deals with subjects of detection, personal protection and resuscitation.

The danger from gas is not always appreciated and is often ignored, because the gas, when pure, has no smell and cannot be seen. Elementary appreciation of the danger of gas will lead to a reduction in the number of gassing accidents, because men will realise that breathing apparatus is available for their protection, instead of thinking of it as a troublesome piece of equipment which hinders them in their work. In plant producing or using large quantities of blast furnace, producer or coke oven gas, risk of gassing by carbon monoxide is always present. Safe working practices and strict supervision on all jobs very much reduce this risk, and the achievement of safe working should be regarded as the direct responsibility of management at all levels and at all times. Gassing accidents often occur when least expected and their severity is reduced if rescue squads and equipment are quickly at the scene of the accident. This can only be achieved if there is a well trained and efficient rescue organisation.

The recommendations of the Sub-Committee are given under several sub-headings, such as, plant design and maintenance; safe working procedure; training; detection of gas; personal protection; treatment; and practice. Particular attention is directed to the Factory Department's Memorandum on Carbon Monoxide Poisoning, which should be followed when isolation of plant is necessary.

These reports are published by the British Iron and Steel Federation; they should be carefully studied by all engaged in the industry and the recommendations given effect in an effort to limit the hazards involved.

Wild-Barfield—N.R.C. Agreement

As a result of an agreement recently concluded with the National Research Corporation of Massachusetts, U.S.A., Wild-Barfield Electric Furnaces, Ltd., are now manufacturing in their works at Watford vacuum melting, heat treatment and analysing equipment of N.R.C. design. The National Research Corporation has had extensive experience in problems appertaining to such vacuum processes, having made and operated more high vacuum furnaces than any other company in the world.

The melting furnaces covered by the agreement are of the arc, induction and resistance types, with capacities ranging from 2 to 3,000 lb. The analytical equipment includes a vacuum fusion gas analysis apparatus for determining the oxygen and hydrogen contents of metals and, in certain cases, the nitrogen content also. For routine tests by producers and users of titanium, there is a specially developed hydrogen-in-titanium analyser.

B.T.H. Contract for Spain

BRITISH THOMSON-HOUSTON has secured an order valued at over £2,500,000 for the supply of hydro-electric plant for the Belesar and Eume Power Stations of Fuerzas Electricas del Noroeste, S.A. (Fenosa) of Coruna, Spain. For both stations material to be supplied includes water turbines, sub-contracted to Boving & Co., Ltd., water-wheel generators, with associated transformers, 220 kV. and 132 kV. switchgear, and power station switchgear and control gear.

The Anodising and Brightening of Aluminium and its Alloys*

Influence of Composition and Structure

By A. W. Brace, A.I.M., C.G.I.A.

Aluminium Laboratories, Ltd., Banbury

There is increasing interest in the possibility of using brightened and anodised aluminium as decorative trim in the automobile and allied industries. Following a description of the chemical and electro-brightening processes currently available, the influence of composition and structure on the response of material to bright anodising is discussed, and general conclusions drawn which are applicable to material required for other anodic finishes.

ONE of the chief characteristics of metals is their distinctive lustre, which in the case of the precious metals is permanent and is unaffected by most agents. The more abundant metals, which are the principal materials used in the engineering industry, do not retain their lustre—copper tarnishes, steel rusts and aluminium acquires a whitish hydrated oxide film. The permanence of the precious metals has long inspired scientists and engineers to devise means of producing a more permanent lustrous finish on the common metals. The main outcome of these efforts has seen fruition in the spectacular growth of the electroplating industry during this century.

By far the greatest output of plated articles is for the mass-production industries—automobile, radio, domestic appliances, etc. These articles are normally of brass, steel or zinc-base die castings, and the enhanced appearance provided by a nickel-chromium plated finish is an important factor in their appeal to the customer. Whilst customer tastes can be influenced by education and careful salesmanship, there is no doubt that the bright, almost mirror-like, finish associated with chromium plate is one which will continue to be demanded by the public as long as a reliable finish can be produced economically.

Aluminium is a metal whose commercial usage dates only from the beginning of this century, but it now ranks by volume as the second most widely used metal. A bright finish is not easily obtained on the metal by chromium plating, since, despite much research, commercial platers have only had limited success with the process. Whilst it could be argued that with a little more effort directed towards translating laboratory results into production practice these difficulties could be overcome, there are other considerations which tend to oppose the adoption of this course.

It is well established that the final performance of the plated finish depends, not only upon plating conditions, but also upon the thickness of the plating, which in the case of nickel-chromium plate is primarily the thickness of nickel deposited. In the case of aluminium the thickness of deposit—copper flash plus nickel—should be fairly high as compared with brass or even steel. Atmospheric exposure tests and limited service trials with

which the author has been associated show that for automobile exterior fittings a deposit of around 0.0015 in. is required for a reasonable performance.

The form of breakdown of a plated deposit on aluminium is a particularly objectionable one, since it usually takes the form of blistering. These blisters appear to give rise to peeling of the deposit by the corrosive attack which takes place at the interface between the aluminium and the plated deposit, due to the difference in potential between the two metals. The cost of plating on aluminium appears likely to be higher than for other metals, owing to the more elaborate conditioning treatments necessary prior to plating, and also to the thicker deposit required. These factors are all difficulties which tend to retard, or even negative, any development of nickel-chromium plated aluminium for the arduous service conditions met with on motor cars, etc.

There already exists, however, an alternative finish for aluminium and certain aluminium alloys which has none of the disadvantages of plating, namely—bright anodising. The protection of aluminium by anodising, i.e. the formation of an oxide film on the metal by making it the anode in an acid electrolyte and passing current, has been practised commercially for about twenty years in Great Britain. Bright anodising depends upon the fact that with high purity metal it is possible, by various electrolytic and chemical treatments, to increase the total reflectivity of a suitably prepared surface, and to retain this by anodising in a suitably chosen sulphuric acid electrolyte.

The brightness obtained on the anodised article is largely dependent upon the composition and metallurgical condition of the material. With the so-called "pure" aluminium, the reflectivity after anodising is a direct function of its purity, increasing with it; so that metal of 99.99% purity, which is now commercially available, represents the highest standard obtainable. Over the past decade much attention has been paid to the commercial development of alloys based on metal of this purity, and their production in fabricated forms, so that outstanding bright anodising characteristics can be obtained. Materials of this type have already been adopted for automobile trim, as an equivalent to chromium plate, by several Continental car manufacturers.

* A thesis successfully submitted for the City and Guilds Insignia Award in Technology.

Production of metal to give satisfactory response to bright anodising calls for the adoption of exacting standards of metallurgical control in production, and certain limits to composition. It is also necessary to adopt appropriate brightening and anodising techniques. In this account it is proposed initially to make brief reference to the main commercial brightening methods, since differences in the response of various materials will subsequently call for slight modifications to the general principles, which will be covered in the main sections dealing with the influence of composition and metallurgical structure on bright anodising. Since bright anodising represents the most critical standard, some indication will also be given of ways in which a lower standard can be adopted on material used for less exacting purposes.

I—BRIGHTENING PROCESSES

In this section it is proposed only to outline the composition and operating conditions of the main brightening processes, their advantages and limitations. A more comprehensive discussion of the probable mechanism of these baths and their composition ranges and operating conditions has been published elsewhere¹ by the author. The processes used fall under two main types—electrolytic and chemical.

Electro-brightening Processes

There exists no agreed definition of the term "electro-brightening," but it can be defined as: "a process in which an increase in reflectivity of a metal object is produced, by the passage of a current, when that object is made the anode in a bath containing a suitable electrolyte and having conditions adjusted to the range in which brightening is produced. It does not produce any appreciable degree of smoothing, as can be obtained from processes usually known as "electropolishing." An obvious corollary is that the object must be highly finished by mechanical polishing before treatment.

The Brytal Process

This was developed by N. D. Pullen, of the British Aluminium Co., Ltd., and patented in 1934.² The aluminium article is made the anode in a bath consisting nominally of:—

Sodium carbonate (anhy.)	15% by weight
Trisodium phosphate...	5% by weight
Water	remainder

and operated under the following conditions:—

Temperature	80° C.
Current density	25–30 A/sq. ft. (initial)
Voltage	12–15
pH	10.0–10.5

The metal is allowed to etch for 15–30 seconds prior to switching on the current, the duration being largely dependent upon the purity of the metal and increasing with it. The length of the electro-brightening treatment is not very critical and is usually around 10 minutes. After this treatment a thin "smudge" film is present on the surface of the brightened article and is removed in a dip of the chrome-phosphoric type.

This process is the most widely used electro-brightening treatment in this country, having the merit that relatively simple equipment is required and the tank need only be of mild steel. Its disadvantage is that it requires a relatively high operating temperature, which can present difficulty in a large tank, due to local tem-

perature differences. Further, care has to be taken in positioning the article in relation to the cathodes and the surface of the electrolyte, owing to the danger of streaking of the metal surface from gas bubbles. Auxiliary cathodes and rotation of the work in the bath may also be necessary with round recessed articles. A high standard of preparation is necessary, and white patches due to overheating of the metal surface in polishing may be revealed after brightening.

The Alzak Process

This was developed by R. B. Mason, of the Aluminium Company of America,³ almost simultaneously with Brytal, but it has had only limited use in this country. A 2.5% by weight fluoboric acid solution is used at 30° C. with an anodic current density of around 15 A/sq. ft. The time of treatment is usually 5–15 minutes, depending upon surface condition and metal purity.

Owing to the corrosive nature of the solution, it is necessary to use a stainless-steel or rubber-lined tank. The acid is rather more expensive than the cheap alkaline materials used for Brytal. Its limitations are similar to those of Brytal, except that it operates at a lower temperature which is not difficult to maintain. The fact that it has not been widely used in Great Britain is probably due to the association of Brytal with the British Aluminium Co., Ltd., who for some years was the sole producer of anodising quality material.

Electropolishing Processes

The main distinction it is proposed to draw between electro-brightening and electropolishing is that the latter is capable of a definite smoothing action. Generally speaking, it is not necessary to have a highly polished surface for these processes to give good results. In fact, a lightly etched surface or one finished with a fine grit "emery" wheel normally provides the best surface for good electropolishing.

Jacquet Type Baths

The original work on electropolishing is usually associated with the name of P. A. Jacquet, who developed the technique for the microscopical examination of metal surfaces so that the true structure could be developed free of the distortion produced by mechanical polishing. The electrolyte most frequently used was a mixture of perchloric acid and acetic anhydride. The original diluent was ether, but other less inflammable organic liquids were subsequently used. Whilst such mixtures found some industrial application, the well-known explosion hazard associated with perchloric acid proved to be its "Achilles Heel," and following an explosion in the United States in 1947 its industrial use ceased.

Phosphoric Acid Mixtures

These are now almost universally employed for industrial electropolishing, and consist essentially of phosphoric acid and either an oxidising agent or a pitting inhibitor. Part of the phosphoric acid may be replaced by another acid capable of dissolving aluminium, such as sulphuric acid.

A typical electrolyte of the class containing an oxidising agent (Type 1) is that covered by a Battelle Memorial Institute patent,⁴ and that containing an organic inhibitor (Type 2) is the subject of a United Anodising Co., Ltd., patent.⁵ The following are the nominal compositions:—

	Type 1	Type 2
Phosphoric acid ..	75% (by volume)	42% (by volume)
Sulphuric acid ..	5%	8%
Chromic acid ..	7%	
Water ..	13%	17%
Cellosolve ..		33%
Temperature ..	80° C.	75° C.
Current density ..	100-150 A/sq. ft.	35 A/sq. ft.

Such electrolytes can give good results on both pure aluminium and aluminium alloys, although there is some evidence that those containing oxidising agents (Type 1) are rather superior to the other type where heterogeneous alloys are being processed.

These electrolytes find application in the finishing of turbine blades, etc., which present problems for normal mechanical polishing. Their principal disadvantage is the high cost of the solution and the possibility of high drag-out losses. Furthermore, the power consumed may be of the order of 2½ kW./sq. ft. and the time of treatment 5-15 minutes: the latter may be a limiting factor in its adoption in mass production industries. Auxiliary cathodes are necessary where there are deep recesses or hollow cylindrical portions. The positioning of the work in the bath is of importance, since it must permit free escape of gas, and where dimensions are critical account has to be taken of the fact that the downward facing portions usually lose more metal than those facing upward. Rotation of the anode may sometimes be necessary.

Chemical Brightening Processes

Recent research has shown it to be possible to produce brightening of aluminium by simple immersion in suitable acid mixtures, which provide local corrosion currents of a sufficiently high order to produce brightening and some smoothing of the surface. Broadly speaking, those compositions based on phosphoric acid have some parallel with the electropolishing solutions containing the same constituents, since they work quite well on the less pure grades and can give a fair degree of smoothing. Those based on hydrofluoric, chromic and nitric acid mixtures tend to resemble the Alzak electro-brightening bath, in that they brighten but have little smoothing action. However, the ammonium bifluoride-nitric acid mixture (Erftwerk process) seems unique, and has a pronounced smoothing action, but only brightens material of around 99.99% purity and some alloys based on this metal. The details of these baths are summarised below, with some comments on their limitations.

Phosphoric Acid Mixtures

These usually consist of 50-80% (by volume) phosphoric acid, 5-12% nitric acid, with the balance made up with sulphuric acid, acetic acid and water, either singly or in combination, and are operated at about 100° C. Tests made by Gromoboy and the present author⁶ show that the presence of water tends to increase the rate of dissolution of the metal, but also extends the life of the bath in making possible a higher aluminium content before it becomes unusable. Acetic acid tends to prevent an appreciable increase in the rate of attack, which otherwise occurs if these baths are operated much above 105° C., with some deterioration in appearance. These baths operate well with most alloys other than those high in copper.

The following compositions have been quoted for commercial mixtures in current use:—

	Alupol III ⁷	Kynalbite ⁸
Phosphoric acid ..	50% (by volume)	78% (by volume)
Nitric acid ..	6.5%	11%
Sulphuric acid ..	25%	11%
Acetic acid ..	6%	
Water ..	12.5%	
Temperature ..	90°-105° C.	95°-110° C.

A small addition of a copper salt is recommended for the first mixture, and of ferrous sulphate for the second. The effect of the addition is not known precisely.

Nitric-Hydrofluoric Acid Mixtures

Several compositions have been patented and these are usually dilute solutions of nitric acid, ammonium bifluoride or hydrofluoric acid, chromic acid and glycerol. Typical compositions taken from the patent literature are as follows:—

	Kaiser ⁹	General Motors ¹⁰
Nitric acid ..	2.5% (by weight)	3.75% (by weight)
Ammonium bifluoride ..	0.6% *	0.65%
Chromic acid ..	0.6%	0.65%
Glycerol ..	0.6%	
Ethylene glycol ..		0.60%
Water ..	bal.	bal.

These are used at boiling point and 3-5 minutes treatment is recommended. Since such solutions are very dilute, frequent replenishment is necessary and there is less flexibility than with solutions based on phosphoric acid. The surface finish must be highly polished if image clarity is important. They are satisfactory for use with the common grades of aluminium and its alloys.

Undoubtedly the most interesting process of this type is the Erftwerk bath,¹¹ which consists nominally of:—

Nitric acid ..	13% (by weight)
Ammonium bifluoride ..	16%
Dextrin/gum acacia ..	1.5%
Temperature ..	50°-75° C.
Time ..	15-30 seconds

It is currently used for brightening of automobile trim, such as is used on the German Volkswagen, Mercedes and other cars. The rapid attack does not lend the process to mechanisation, since the transfer mechanisms do not readily respond to so short a cycle. In Germany the brightening is carried out by hand dipping and the racks handled by conveyor after this treatment. However, it is only satisfactory if the total of elements present, other than aluminium and magnesium, does not exceed about 0.10%. This will be discussed in a later section.

II—INFLUENCE OF COMPOSITION ON RESPONSE TO BRIGHTENING AND ANODISING

In this section composition will be discussed in relation to the behaviour of the material in anodising and brightening. It must be appreciated that the bright anodised finish is the most searching and critical method of assessing the quality of a commercial product. Whilst most of the subsequent material is relevant to "natural" or "matt" anodic finishes, it is the bright finish which clearly shows the influence of composition and structure. Although the latter is influenced by the former, some separation of the two is necessary in order to understand basic principles.

To obtain the maximum brightness after anodising, it is essential that the material should be free from impurities and homogeneous. The influence of purity on brightness has been studied, and Fig. 1 shows the values obtained by Pullen¹² for material Brytal-treated and anodised. Whilst the total reflectivity decreases almost

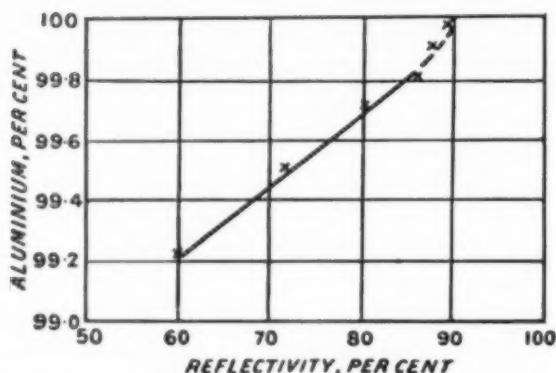


Fig. 1.—Effect of purity on brightness obtained after Brytal electro-brightening.¹²

linearly with impurity content, the decrease in specular reflectivity is even greater. This in turn means that the image clarity of the brightened surface is also affected, and the increase in the diffuse component is often a useful measure of this. The decrease in specular reflection is also greater as the anodic film thickness is increased. To a smaller degree the impurities and alloying elements present will affect the behaviour in brightening, although the effects vary somewhat according to the technique used. It is necessary to consider the mechanism of both brightening and anodising to explain these phenomena.

Effects of Composition on Brightening

It is desirable to subdivide the discussion into two sections, since there are basic differences between the chemical and electro-brightening processes.

Effect on Electro-brightening and Electropolishing

It is considered that an important feature of these processes is the production on the surface of the metal of a porous oxide film, whose rate of formation is in equilibrium with its rate of dissolution. The film is probably thinner on the peaks than in the valleys, since more current would be expected to flow through the former. If it is assumed that the current distribution throughout the bulk of the metal is uniform, as shown in Fig. 2, then with a roughened surface the current on the peaks will be greater, due to the increased number of available points for transmission of current. In Fig. 2 the lines are intended to represent the intensity of current distribution.

Smoothing proceeds by the diffusion of metals into the electrolyte, with greater diffusion taking place on the high spots. In phosphoric acid based electrolytes, there almost certainly exists a viscous layer of reaction products next to the oxide film. It has been shown by Edwards¹³ that in the electropolishing of copper in phosphoric acid electrolytes, the rate of polishing depends upon the diffusion gradient existing across this viscous layer, and that the more concentrated electrolytes tend to give greater smoothing than dilute ones.

The influence of elements present either as impurities or alloying elements, assuming them to be uniformly distributed, will depend upon whether they are soluble or not in the electrolyte. Thus, in the Brytal process the constituents containing iron and silicon are slightly attacked and some removal occurs, whilst with phosphoric acid electrolytes dissolution of these constituents occurs and a slightly smaller diffuse component can be expected from metal of around 99.5% purity treated

this way, as compared with Brytal. The total reflectivity will be higher due to the presence of a virtually pure aluminium surface after brightening.

Magnesium is often added as an alloying element to aluminium, and in solid solution its effect on electropolishing in phosphoric acid electrolytes is small, but with Brytal the presence of magnesium oxide, which is relatively resistant to alkaline attack, raises difficulties, and it is usually necessary to increase slightly the sodium carbonate content and the temperature to overcome this. Even so, a magnesium content of around 1.5% appears to be the working limit commercially.

The presence of small amounts of other elements, such as copper, in solid solution makes very little difference to brightening, in fact, claims have been made that about 0.25% copper improves the response to brightening. When several per cent. of that element is present in the form of CuAl_2 , or constituents such as Al-Cu-Fe or Al-Cu-Ni ternary phases, then the effect of these aluminide-forming elements may be serious, since they are of different potential from the groundmass and are weak points in the oxide film. When electrolytes of the phosphoric acid—Cellosolve—water type are used, local attack may occur around these constituents. If they contain strong oxidising agents, such as chromic acid, then this can be prevented and electropolishing takes place, although the results are not quite of the high order obtained with high purity aluminium.

Effect on Chemical Brightening

Chemical brightening is probably produced by a mechanism not dissimilar from that of electro-brightening, except that the current required to promote smoothing is due to local corrosion cells and not to an external source. These high currents are associated with the use of higher temperatures than in electro-brightening (up to 100°C.) and concentrated acids. A strong oxidising agent, usually nitric acid, is invariably employed to obtain satisfactory results.

Impurities are more important in chemical brightening as they have a more pronounced effect, probably due to the thinner oxide film, since the thickness of any oxide film is proportional to the product of the applied potential and a constant for the given electrolyte.¹⁴ As was indicated for electro-brightening, the effect of impurities depends upon their metallographic state. Elements in solid solution have little effect, and here again a beneficial effect is claimed for small amounts of copper in materials chemically brightened in phosphoric acid based mixtures.

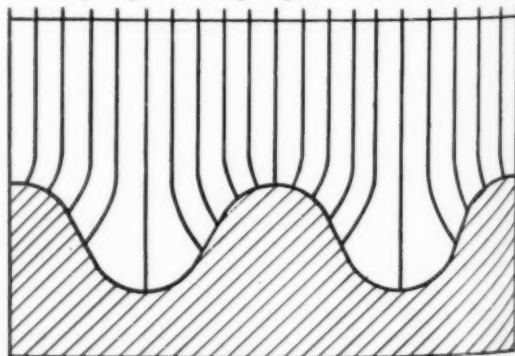


Fig. 2.—Distribution of current on uneven metal surface during electropolishing. The distance between the lines represents the current density.

With insoluble elements forming aluminides, the results obtained are again influenced by the presence of these constituents. In phosphoric type mixtures, rather better results than are possible with Brytal treatment can be obtained on commercial purity aluminium, due to the fact that these impurities may be almost completely dissolved from the surface, thus leaving a metal surface of much higher purity than the basis material. Elements in solid solution, such as magnesium or the quasi-binary magnesium-silicide, seem to have little effect in phosphoric brightening, but impurities of more than about 1% (by weight) cannot be tolerated, since they tend to promote local preferential attack. Support for these views can be found in the papers by Fischer and Koch¹⁵ and Koch and Keste¹⁶ reporting electron microscope studies of chemically and electro-brightened surfaces.

However, the Erftwerk chemical brightening bath has certain unique features which indicate that its mechanism is different from those based on phosphoric acid, and this in turn profoundly influences its response to materials containing impurities. In fact, it will only give satisfactory results when used on 99.99% aluminium, or at least on aluminium of 99.95% purity. This is probably due to the high current and potential operating with this solution, since Fischer and Koch¹⁵ calculate the galvanic current generated to be 5-10 A./sq. cm. in the Erftwerk bath, as compared with 0.3 A./sq. cm. in a commercial phosphoric chemical brightener. Further, Straumeris²⁷ has shown that the dissolution potential of aluminium in hydrofluoric acid is around -1.5 V., and that the presence of iron lowers this potential by a further 0.2 V. It would seem therefore that high currents are generated in the neighbourhood of impurities, thus leaving them as small mounds surrounded by a moat.

The pronounced fall in reflectivity produced by iron in pure aluminium Erftwerk brightened and anodised is shown by Fig. 3. However, this process is more critical in respect of alloying additions which normally go into solid solution. If magnesium has been added in the order of 0.5% or greater, and the manufacturing technique has not ensured complete homogeneity, then preferential attack in the form of streaks following the direction of rolling will be produced. This is obviously due to local differences in potential associated with non-uniform distribution of the magnesium atoms. It is even possible to detect a slight "pebble" effect with material of moderate grain size, which appears to be associated with some preferential attack at the grain boundaries. On the other hand, if the manufacturing technique is correct, it is claimed by Helling and Neunzig¹⁷ that on 1% and 2% magnesium alloys based on super-purity aluminium, the specular and total reflectivities obtained after Erftwerk brightening are superior to those obtained after treatment in a commercial phosphoric brightener. This has been confirmed by unpublished work carried out at Aluminium Laboratories, Ltd. It is also stated by Vereinigte Aluminium Werke that iron or copper in solid solution is capable of reducing the response to brightening, and that the limits of these elements should be around 0.005% max.

Effects of Composition on Anodising

The formation of aluminium oxide on the metal takes place according to the equation:—

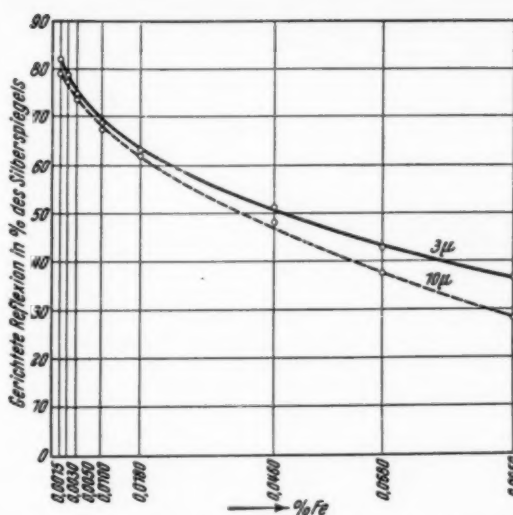


Fig. 3.—Effect of iron content on the total reflectivity of aluminium (expressed as a percentage of that of a silver mirror) after Erftwerk brightening and anodising.¹⁷

When formed in air, the oxygen is derived from the atmosphere, but in anodising it is obtained from the sulphuric acid electrolyte. The mechanism is by no means simple, although for our purposes the basic features will be adequate.

In anodising, the oxygen ions migrate to the anode and combine with the aluminium ions migrating to the surface to form an anodic film, whilst hydrogen is evolved at the cathode. The mechanism of formation of this anodic coating, is, however, not as simple as would appear from this statement, since the action would obviously cease as soon as the anodic film covered the surface and had sufficient resistance to prevent the flow of current.

In oxide solvent electrolytes, there tends to be formed initially, according to Hunter and Fowle,¹⁴ a non-porous oxide layer similar to that produced in non-solvent electrolytes where the thickness is 14 Å/V. Before this thickness is reached, the solvent effect comes into play and local thin spots form; the current consequently flows more freely, thus causing a build-up of oxide around this point and forming an oxide cell. This process is multiplied over the whole surface, the dimensions of the oxide cells being only a few hundred Angstrom units.

As long as the rate of growth is in excess of the rate of dissolution of the coating, the film will continue to grow, and under efficient commercial conditions the growth of the film up to at least 10μ thickness is directly proportional to the number of ampere-minutes of energy used. Throughout anodising, therefore, there will be a continued migration of aluminium ions to combine with oxygen ions. In turn, ions of impurities or alloying elements will also enter into this reaction and give an imperfect film, so that some lowering of total reflectivity and loss in clarity may be expected after anodising, its extent depending upon the thickness of the film and the nature of the other elements present.

Influence on Clarity of Film

As already indicated, any element present in the metal or alloy being anodised will affect response to anodising.

TABLE I.—SOME PHYSICAL PROPERTIES OF OXIDES OF METALS FREQUENTLY PRESENT IN ALUMINIUM AND ITS ALLOYS

Oxide	Colour	Refractive Index	Oxide	Colour	Refractive Index
Al ₂ O ₃	white, transparent	1.65	Fe ₂ O ₃	red-brown	2.78-3.01
Cr ₂ O ₃	green	2.5	SiO ₂	transparent	1.43-1.57
Cu ₂ O	brown	2.70	TiO ₂	white	2.50
CuO	black	2.63	Mn ₂ O ₃	black	2.15-2.46
Fe ₃ O ₄ .H ₂ O	yellow	2.05-2.31	MgO	white	1.736
			ZnO	white	2.00

If the particular element is very soluble in the electrolyte, then little of it may remain in the anodic coating, but its precise influence will depend on whether it is in solid solution or present as an intermetallic compound. When in solid solution, the proportion of the oxide of the foreign element present in the anodic coating will depend upon the concentration of the element in the solvent, its electrochemical equivalent, and the relative solubility of its oxide in the electrolyte compared with aluminium oxide. This in turn will have an effect upon the clarity and general characteristics of the anodic coating.

It is well known that magnesium is normally added to aluminium where an alloy with a good clear anodic film is required. Similarly, copper in aluminium alloys is known to tend to darken the film, whilst zinc tends to produce a slightly milky coating. All these effects are optical ones which must be associated with the characteristics of the oxides of these metals as present in the anodic coating.

As far as the writer is aware, no data have been published on this subject, but reference to the physical properties of metallic oxides¹⁸ gives a good indication of the reasons for these effects. Table I gives data for refractive index and colour of the oxides of metals commonly present in aluminium, either as impurities or as alloying elements.

It can thus readily be appreciated why magnesium is an element eminently suited for alloying with aluminium which is subsequently to be anodised. Magnesium oxide in finely divided form is white, as is aluminium oxide, and their refractive indices are similar. When these oxides are formed anodically on an aluminium-magnesium alloy, they give a clear transparent coating. The darkening of the films in the presence of iron, manganese and copper is also readily explained by the high refractive index of their oxides and their characteristic dark colour.

The case of silicon is an interesting one, since alloys high in silicon are normally dark in colour after anodising, but its oxide is transparent and the refractive index reasonably near to that of aluminium oxide. It is reasonable to assume therefore that the anodic film should be clear, and where small amounts of silicon are completely in solid solution this appears to be the case. For example, extrusions in HE10W normally contain some excess silicon but usually give a clear anodic film. A magnesium-silicide alloy offered by one manufacturer, containing 0.5% magnesium, 0.3% silicon, 0.25% copper, also gives a clear anodic film and will electro-brighten.

The reason for the darkening in the presence of free silicon is probably associated with the fact that metallic silicon has a very high electrical resistance— 85×10^3 microhm. cm.—so that local heating is produced around the silicon particles and a correspondingly high current density. Small particles of undissolved aluminium may become entrapped in the anodic film growing under these conditions, and result in the coating appearing black. A similar effect is found in producing hard anodic

TABLE II.—BEHAVIOUR OF ALUMINIDES IN SULPHURIC ACID ANODISING

Constituent	Effect	Constituent	Effect
MnAl ₃	Slightly attacked	Al ₃ Mg ₂	Moderate attack
FeAl ₃	Slightly attacked	Al ₃ Zn ₄	Strongly attacked
CuAl ₂	Slightly attacked	Mg ₂ Zn ₃	Strongly attacked
Mg ₂ Si	Complete dissolution	Al ₃ Mg ₂ Zn ₃	Complete dissolution

coatings under conditions of high current density and low electrolyte temperature. There is also evidence of entrapped silicon particles which would have a similar effect.

With zinc and titanium the well-known opacity of these oxides as pigments needs no elaboration. Titanium is normally used, if at all, as a grain refiner and in amounts not greater than 0.05%, so that it is not usually of direct importance, although it does reduce total reflectivity. It is produced in the form of its oxide in the anodic film produced by the Ematal process, which includes titanium oxalate in the electrolyte. This is decomposed to produce titanium oxide which forms along with the aluminium oxide at the anode. The "miliness" of anodic coatings on zinc-containing alloys is again a function of the higher refractive index of zinc oxide.

When the added element forms an aluminide, then the effect on response to anodising depends upon its reactions in the electrolyte. Fischer, Budiloff and Koch¹⁹ have shown that these fall into two categories—those attacked strongly by the electrolyte and those only slightly attacked. The findings are summarised in Table II.

Whilst CuAl₂ is not strongly attacked when anodised by itself, as in Fischer's work,¹⁹ the difference in potential between the constituent and the adjacent solid solution is usually such as to cause pronounced attack at the boundary, resulting in particles of the constituent falling out. The element silicon does not form an aluminide, and Fischer found that it was not readily converted to oxide in anodising. Magnesium silicide (Mg₂Si) is not normally found in wrought alloys as a second phase, so that alloys containing magnesium and silicon behave as if there were small amounts of these two elements independently present in solid solution.

Influence on Rate of Anodising

With solid solutions, it would be expected that the rate of anodic film growth would be proportional to the concentration of the solute element and its electrochemical equivalent, provided its oxide is not appreciably more soluble in sulphuric acid than is aluminium oxide. Table III gives the electrochemical equivalents for aluminium and the main alloying elements and impurities.

On this basis alone, the effect of alloying elements would be small, since the oxidation rate of an aluminium-5% magnesium alloy would only be—

$$0.95 \times 0.093 + 0.05 \times 0.126 = 1.018 \times \text{that of pure}$$

aluminium.

Values obtained by Herenguel and Segond.²¹

TABLE III.—ELECTROCHEMICAL EQUIVALENTS OF ELEMENTS PRESENT IN ALUMINIUM AND ITS ALLOYS

Element	Valency	E.C.E. (mg./coul.)	Element	Valency	E.C.E. (mg./coul.)
Aluminium	3	0.0934	Magnesium	2	0.1260
Chromium	6	0.0898	Manganese	4	0.1425
	3	0.1796		2	0.2846
Copper	2	0.3294	Nickel	2	0.3041
	1	0.6588	Silicon	4	0.0727
Iron	2	0.1929	Zinc	2	0.3384
	2	0.2893	Titanium	4	0.1241

TABLE IV.—FILM THICKNESS OF ALUMINIUM-MAGNESIUM ALLOYS ANODISED 45 MINUTES IN 10% (BY VOLUME) SULPHURIC ACID AT 20° C.

Alloy	Film Thickness (μ)	
	Constant 15 V. voltage	Constant 1.2 A./sq. dm. current
99.5% Al	12	11.0
Al-3% Mg	15	12.0
Al-5% Mg	19	12.5
Al-6.5% Mg	23	13.0

however, show that the oxidation rate is increased far more than the 2% indicated merely from considerations of electrochemical equivalent. This can be demonstrated in two ways: (1) by the film thickness obtained when anodising at constant voltage; and (2) by the film thickness obtained with constant current density, the former giving the more pronounced effect. Table IV summarises the results obtained by these workers.

The higher film thicknesses obtained with constant voltage may be explained by the fact that the resistivity of magnesium oxide is probably lower than that of aluminium oxide, and that it is more soluble in sulphuric acid. (The heat of formation of MgSO_4 is 301 k.Cal. compared with 357 k.Cal. for $\frac{1}{2} \text{Al}_2(\text{SO}_4)_3$). This would result in a higher current passing for a constant voltage. With a constant current, the effect is much smaller, but still significantly more than can be deduced from simple theory. It is not possible on the basis of present knowledge to offer an adequate explanation for this behaviour, and more work is needed. This could commence with the determination of anodic film thicknesses of solid solution alloys in non-solvent (e.g. ammonium borate) electrolytes, and of dissolution rates of oxides of alloying elements in hot sulphuric acid electrolytes.

The results obtained by Herenguel and Segond are not wholly in accordance with earlier investigations of Fischer, Budiloff and Koch,^{19, 20} who anodised aluminium-magnesium alloys containing 3%, 5%, 7% and 9% magnesium, in 25% (by weight) sulphuric acid electrolyte at 20° C. at a constant current density of 2 A./sq. dm. They obtained only small differences in film thickness for the different alloys (19–21 μ) and these were not directly related to magnesium content. Undoubtedly, in this strong electrolyte, dissolution of the film or, indirectly, of the metal, was probably a more important factor, and certainly the higher metal losses given in the paper for the 7% and 9% magnesium alloys as compared with the 3% alloy would have increased the coating weights of the first two alloys by 1 μ . This is best appreciated by a study of Table V, in which the last column gives the film thickness which would be obtained with the alloys if their anodising efficiency were the same as for the pure metal.

These results, whilst not entirely in agreement with Herenguel and Segond, show the same trend. The greater relative amounts of magnesium dissolved in the

TABLE VI.—ANODIC COATING THICKNESS AND METAL LOSS FOR VARIOUS WROUGHT ALLOYS IN THE HOMOGENISED CONDITION WHEN ANODISED IN 25% (BY WEIGHT) SULPHURIC ACID AT 2 A./SQ. DM. AND 20° C.^{19, 20}

Alloy	Film Thickness (μ)	Weight Loss (gm./sq. dm.)					Film Thickness (corrected to aluminium efficiency)
		Al	Mg	Zn	Cu	Total	
99.99% Al...	19.0	140	—	—	—	140	19.0
Al-4% Cu...	17.0	156.2	—	—	14.4	170.6	18.2
Al-Cu-Mg...	17.6	186.3	5.9	—	14.9	207.1	20.2
Al-Mg-Si...	20.6	140.3	—	—	—	140.3	20.6
Al-1.5% Mg-4.85% Zn	23.5	151.2	17.6	14.0	—	182.2	24.8
Al-2.6% Mg-4% Zn...	17.6	142.6	10.3	4.5	—	157.4	18.2
Al-5% Mg-4.85% Zn	29.4	146.6	9.4	11.5	—	187.6	30.9

electrolyte with increase in magnesium content show that magnesium oxide is relatively more soluble. Fischer, Budiloff and Koch also made similar measurements on an aluminium-copper-magnesium alloy (duralumin), an aluminium-4% copper alloy, an aluminium-magnesium-silicon alloy, and various aluminium-magnesium-zinc alloys in the solution heat treated condition. The results are summarised in Table VI.

It can be seen that the aluminium-copper alloys give a lower film thickness, but if allowance is made for the metal dissolved, then the anodising efficiency is roughly that for pure aluminium. The effect of copper in solid solution is therefore to increase the tendency of the coating to dissolve in the electrolyte. The aluminium-magnesium-silicon alloy gives a slightly greater film thickness, as would be expected from its higher electrochemical equivalents and low concentrations. Two of the aluminium-magnesium-zinc alloys give very high film thicknesses despite high dissolution values, whilst the third appears to be anomalous.

It is usual in commercial anodising to anodise at constant voltage, so in this respect Herenguel and Segond figures for anodic film thicknesses of various alloys anodised for 45 minutes at 15 V. in a 10% (volume) sulphuric acid electrolyte at 20° C. are of practical interest. They obtained a film thickness of 12.0 μ for 99.5% aluminium, 12.5 μ for an aluminium-magnesium-silicon alloy, and 6.5 μ for an aluminium-copper-magnesium alloy. The values for the aluminium-magnesium alloys have been given in Table IV.

Thus, it can be said that the wrought homogeneous aluminium-magnesium alloys show a small but definite increase in oxidation rate at constant current density and a very pronounced increase when anodised at constant voltage. Aluminium-zinc-magnesium alloys appear to have even higher oxidation rates than the binary aluminium-magnesium alloys. Aluminium-copper alloys have a lower oxidation rate under both constant current and constant voltage conditions. Aluminium-magnesium-silicon alloys have slightly higher oxidation rates than pure aluminium and, from the author's observations, the aluminium-1 $\frac{1}{4}$ % manganese alloy behaves similarly.

When alloys are in the heterogeneous condition, the film thickness will be governed to some extent by the amount of second phase present and its reaction in anodising. Fischer, Budiloff and Koch¹⁹ prepared intermetallic compounds and cast them into 30 × 30 × 5 mm. slabs, anodising them at 2 A./sq. dm. in a 25% (by weight) sulphuric acid electrolyte at 20° C., and determined the relative amounts of metal dissolved. These values are reproduced in Table VII. This shows that whilst the MnAl_6 constituent is slightly less soluble

TABLE V.—ANODIC COATING THICKNESS OF ALUMINIUM-MAGNESIUM ALLOYS AND METAL LOSS IN ANODISING AT 2 A./SQ. DM. IN A 25% (BY WEIGHT) SULPHURIC ACID ELECTROLYTE AT 20° C.^{19, 20}

Alloy	Film Thickness (μ)	Weight Loss (g./sq. dm.)			Film Thickness at Aluminium Efficiency (μ)
		Al	Mg	Total	
99.99% Al	19.0	140	—	140	19.0
Al-3% Mg	20.6	135.7	3.8	139.5	20.6
Al-5% Mg	19.1	146.2	6.6	152.8	19.5
Al-7% Mg	19.1	157.1	7.5	164.6	20.1
Al-9% Mg	20.6	147.7	12.7	160.4	21.4
Al-9% Mg (super pure base)	21.1	147.3	14.8	162.1	22.0



Fig. 4.—“Reticulation” on 99.99% aluminium after brightening and anodising, due to inadequate breaking down of original coarse grained cast structure.²⁴

than pure aluminium, CuAl_2 and FeAl_3 have somewhat greater solubility. However, Zn_3Al_2 , MgZn_2 and Al_3Mg_2 are very appreciably dissolved, whilst Mg_2Si and $\text{Al}_2\text{Mg}_3\text{Zn}_3$ completely disappear. Silicon shows a rather lower weight loss than aluminium when anodised in sulphuric acid, since it is relatively unattacked.

These results also indicate that the presence of intermetallic constituents will affect the appearance of the anodised material, since, although the anodic film will eventually bridge any depression due to dissolution of the intermetallic constituents, this will result in a matt grey or greyish-white appearance due to absorption and scattering of light. The anodic coating efficiency, i.e. weight of coating formed will also tend to be lower in a weight of metal dissolved heterogeneous material. Obviously, intermetallics should be as low as possible for clear bright anodic finishes, and, as already indicated, their virtual absence is necessary when producing the equivalent of a “chromium plate” finish.

III—EFFECT OF METALLURGICAL STRUCTURE ON RESPONSE TO BRIGHTENING AND ANODISING

Anodising is a unique process in that, not only does it provide a good protective coating, but it very faithfully reveals and reproduces some of the important metallurgical features of the material, thus lending itself to adaptation as an investigational technique by the research worker. Certain precautions have to be taken to ensure it is properly used, and its limitations must also be appreciated, but it will give useful information on

TABLE VII.—WEIGHT LOSS OF INTERMETALLIC COMPOUNDS WHEN ANODISED FOR 30 MINUTES IN 25% (BY WEIGHT) SULPHURIC ACID AT 2 A./SQ. DM. AND 20° C.¹⁸

Constituent	Weight Dissolved (g./sq. dm.)	Constituent	Weight Dissolved (g./sq. dm.)
Al	0.140	MgZn_2	2.43 Mg
MnAl_6	0.120 Al	13.9 Zn	
.. .. .	0.001 Mn	Al_2Zn_3	0.107 Al
FeAl_3	0.146 Al	3.14 Zn	
.. .. .	0.070 Fe	Mg_2Si	all
CuAl_2	0.120 Al	$\text{Al}_3\text{Mg}_2\text{Zn}_3$..	all
.. .. .	0.080 Cu	Si	0.100 Si
Mg_2Al_3	0.500 Al		
.. .. .	0.270 Mg		

the uniformity of structure and thermal history of a material.

The principal contributions to the development of this technique have been made by French metallurgists Lacombe and Herenguel and their colleagues.²¹⁻²³ The following are the principal techniques developed.

(1) Electropolishing the material in a Jacquet type electrolyte and then anodising in a typical sulphuric acid anodising bath and sectioning the anodised samples. This shows variations in the composition of the solid solution within a grain, since the thickness of anodic coating varies with the amount of alloying element in the solid solution immediately adjacent, from which it has been formed.

(2) Using the technique given in (1) but stripping the film in a chrome-phosphoric mixture which does not attack the metal, and then examining the electropolished surface. Local attack due to precipitation at the grain boundaries or impurities is more readily revealed than by conventional etching techniques.

(3) If the appropriate electropolishing and anodising technique is employed, it is possible to detach the anodic film from the metal and examine it under polarised light. Taken in conjunction with etch pits produced by subsequent treatment of the surface, this technique can be used to detect changes in the orientation of the structure and to confirm features shown by methods (2) and (3).

(4) A modification of method (3) consists of anodising the electropolished specimen in an ammonium borate or tartrate electrolyte, which produces a structureless film which can be detached and used for the production of formvar replicas for examination with the electron microscope. This technique is particularly useful for studying precipitation phenomena.

Production of Anodising Quality Sheet and Strip

In the following sections it is proposed to discuss briefly the possible defects which can arise in preparing material for anodising—particularly bright anodising—and their elimination. Whilst the preliminary manufacturing operations are similar whether sheets, extrusions or forgings are to be produced, it is more convenient to consider them separately.

Effect of Casting Conditions

As is so often the case, many of the defects in sheet for bright anodising originate from the original cast ingot. It has been found, particularly by Herenguel,^{23, 25} that the grain size of the ingot has a definite influence on the incidence of a characteristic defect in the sheet after brightening and anodising which is known as “reticulation.” This defect (Fig. 4) appears as a network of lines on the surface which appear either dark or light relative to the metal, depending upon the conditions of illumination.

This defect is more prevalent in metal of 99.5–99.8% purity, although it has been observed in material prepared from 99.99% ingot. Its origin can be explained by reference to the manner in which deformation of the ingot proceeds. It is well known that impurities tend to segregate to the grain boundaries, and that in solid solution alloys the composition at the grain boundaries differs from that of the metal in the grains.

When the preheated ingot is rolled, there will tend to be a lack of cohesion at the grain boundaries due to the

structural differences indicated in the preceding paragraph. With fine grained ingot this will be of minor importance, but with a large grain size the stresses imposed may be sufficient to produce de-cohesion at the grain boundaries and the formation of minute cracks. This condition is shown in Fig. 5. Although subsequent rolling tends to heal these cracks, they are usually revealed again after brightening and anodising, but removal of some of the surface by a light emery bobbing and polishing may be sufficient to remove the defect, if it is not severe.

On the other hand, reticulation may be due to micro-cracks in the billet arising from hot tearing during casting. Where this is the case, the incidence of the defect will not necessarily be related to as-cast grain size. Reticulation has no direct relation to the grain size of the final product, but it has a direct relation to the as-cast grain size, since it is in material produced from cast ingots of large grain size, particularly if columnar crystals are present, that this defect will be most in evidence.

It is obvious that there must be close control over the grain size of the ingot during casting and over the soundness of the billet, or some other technique must be adopted to avoid this defect. Control of grain size can be effected by control of pouring rate, casting temperature and rate of cooling of the ingot, but even these are still dependent to some degree upon the human element. It is also unfortunate that the higher the purity of the metal the more susceptible it becomes to developing a large grain size. A further point to be watched with alloys containing magnesium is the possibility of oxide inclusions becoming trapped in the metal, since these stand proud of the surface after brightening.

With metal of 99.5-99.8% purity, control of grain size is frequently obtained by additions of small amounts of grain refiners such as titanium, boron or titanium boride. These are fairly effective in that they reduce the degree to which these difficulties are encountered, although they do not necessarily always eliminate them. However, the tendency of titanium to reduce slightly the brightness after anodising should be noted (see Section II), and its content will generally have to be restricted to less than 0.02%. Boron is somewhat less critical in this respect.

With metal based on 99.99% purity ingot the problem is somewhat different. Whilst titanium, particularly if present to an extent sufficient to form $TiAl_3$, will reduce brightness after electro-brightening, the effect on Erftwerk chemical brightening will be more marked, and quite small amounts (0.01%) will produce a marked drop in brightness. Owing to the low impurity level at the grain boundaries, intergranular cohesion is higher than for lower purities and reticulation does not occur so readily. However, large grain size tends to produce an undulating "pebbly" appearance, particularly after chemical brightening by either Erftwerk or phosphoric acid brighteners. Close control of casting conditions will therefore remain an important first step in the production of bright anodising quality super-purity aluminium and alloys based on it. It will be easier to maintain a

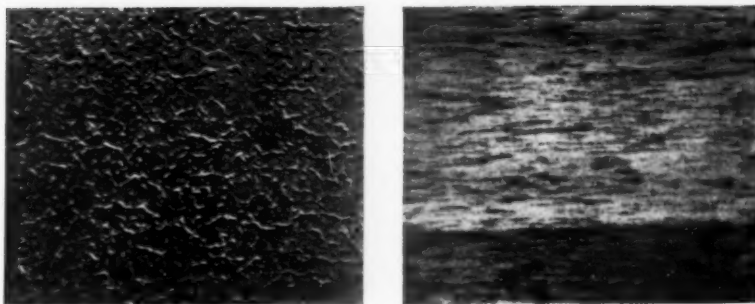


Fig. 5.—Left: surface condition of an aluminium-3% magnesium alloy after hot rolling under unsatisfactory conditions; right: same surface after cold rolling.

satisfactory grain size with the alloys, since concentration gradient effects tend to give a slightly finer grain size.

It has been established that extrusion of the ingot prior to rolling will eliminate reticulation and generally facilitate the production of a uniform product. Obviously, the objections to it are the relatively high cost of the operation and the limitations it places on the size of slab which can be rolled, thus tending to confine its application to products produced by costly flat sheet mill operations. To meet the output demands of the motor industry or other mass production industries, strip mill production techniques are essential.

A necessary part of ensuring freedom from surface defects is careful scalping of the ingot to remove surface segregation and such defects as "blebs," oxide inclusions and laps. This is, of course, standard practice in the production of clad high strength alloys, and techniques have already been devised for rapid scalping at low cost.

Adequate soaking of the ingot is always important, but for anodising quality material it is more critical. If pre-extruded stock is used, then soaking can follow normal techniques, since the structure is well broken down and uniform. Where it is necessary for economic reasons to break down the cast ingot direct, it is important to ensure that thorough homogenisation of the ingot has occurred in preheating. This involves soaking for a slightly longer time at a higher preheat temperature (around 500° C.). If this is not done the final product will show a difference in texture in the form of a regular streakiness in the rolling direction, of different tint from the background, mainly on the alloys. Such an appearance is due to lack of uniformity of composition within the grains.

Control of Rolling Procedure

The first rolling stage is breaking down on the hot mill, and in this respect control of lubrication is important, to prevent hot mill pick-up due to local welding and tearing of the ingot by the rolls, as a result of local lubrication failure. Tears produced at this stage may subsequently be partially welded and flowed over to give a satisfactory visual appearance, which will be destroyed once the flowed surface layer has been removed. This defect will show itself in the form of slightly elongated streaks whose extent depends upon the amount of the defect present originally and the total reduction.

Some attempts have been made to reduce this difficulty by light wire brushing of the rolls to remove the

pick-up. There is a danger that too coarse a wire brush will be used with too high a pressure, thus scoring the rolls. This, in turn, can lead to the appearance of a defect called "pointillage" by French metallurgists, which is in the form of small dots or streaks reproduced from the uneven hot mill surface.

To eliminate the possibility of hot mill pick-up being present in the final product, caustic pickling of the hot mill slab prior to cold rolling is often practised. Once again this operation presents problems, since not only does pickling add to the cost, but there are obvious practical limits to the size of tank which can be used, and hence to the size of hot mill slab which can be pickled. To date, this limitation has not been too serious, since the demand for bright anodising quality sheet has been small, but the possibility of large tonnage demands from the mass production industries necessitates a re-examination of the problem.

Normally, caustic pickling requires at least a 5 minute duration of treatment to be effective. One possible approach is to devise a plant for pickling of coiled hot mill strip with de-coiling and re-coiling equipment added. However, the treatment time is lengthy and the plant is likely to be rather large. Certainly a shorter treatment time would be desirable. The function of pickling seems to be to remove oxide from the surface and, probably, to bring about some smoothing action. It might be attractive to use the Erftwerk bath for this operation, since 30 seconds treatment will remove around 0.002 in. of metal. This would have the advantage of high rate of output and ease of control.

Cold rolling presents few problems peculiar to bright anodising material. The rolls have to be ground more carefully and better maintained than for general commercial work, and the choice of lubricant, so as to avoid staining during annealing treatments, is obviously important. Precautions to avoid contamination from airborne grit have also to be applied, such as the provision of canopies over the rolls, and greater care has to be exercised in handling the sheet.

Material for bright anodising requires a recrystallisation annealing treatment, although it may subsequently be temper annealed to the required degree of hardness. Published information on this subject relates primarily to super-purity 3% and 5% magnesium alloys. According to Herenguel and Scheidicker²⁸ the minimum cold reduction should be not less than 25%, so as to avoid grain growth, nor should it exceed 300%. The minimum annealing temperatures are given as 325° C. for the 3% alloy and 270° C. for the 5% alloy.

If these limits are not observed, there is a tendency for the magnesium atoms to segregate along the grain boundaries of the material as-rolled, as opposed to the boundaries of the recrystallised grains, and thus give a mottled streakiness on anodising. With alloys of 1.5-2.0% magnesium content a recrystallisation temperature of about 350° C. seems desirable. Obviously the degree of cold work and the recrystallisation time and temperature have to be chosen so as to give a reasonably fine grained material. A grain size not exceeding 150-200 μ in the longitudinal direction and 50-70 μ transversely appears to represent a reasonable commercial standard.

Discussion

The technique for mass production of bright anodising quality strip is still in an early stage of development,

and there is an obvious need for improvements, particularly at the hot mill stage. One possible approach for thicker gauge material is to consider the marrying of existing techniques. In North America, anodising quality material has been produced for some years by cladding a commercial material, usually 99.2% purity, with a higher purity layer, such as 99.7% purity. This is usually done with material that has not been pre-extruded, but the clad layer has already been heavily worked prior to re-rolling, so that the hot mill breaking down reduces it still further and is nearly as effective as pre-extrusion.

With aluminium-magnesium alloys, whether of high or super-purity base, the advantage of pre-extrusion is that not only is the cast structure well broken down, but also greater uniformity of magnesium distribution is obtained. One might therefore consider the use of extruded slabs instead of cladding on the cast ingot, and thus reduce the need for high preheat temperatures and long soaking times. This would impose some limitations on the width of the ingot going into the hot mill. However, the width of strip required for much of the car trim is unlikely to exceed 12 in., so that the use of specialised narrow strip mills could be considered if demand were sufficient, and width limitations on the cast ingot would be less important. Alternatively, there would be merit for less exacting requirements to clad the material with slab already preheated to high temperature and rolled under appropriate conditions, using the same composition for core and cladding, and relying on cladding to produce the necessary refinement in structure. It may also be necessary to adopt a high strength core material clad with a super-purity base material for strength applications such as bumpers.

Most of the above remarks apply to bright anodising quality material, but the basic principles apply to all anodising qualities. Obviously, for large panels such as may be required for architectural applications, the standards will be less exacting and the use of clad material should give quite satisfactory results if a few other precautions are taken. The technique adopted for production of any anodising quality material will obviously be governed by the requirements of the customer and the price he is prepared to pay for a given standard of finish.

Extrusion Technique

It is not quite so difficult to produce anodising quality extrusions as it is anodising quality strip. The same careful control of casting conditions is important and the billets should be scalped prior to preheating, to avoid the possibility of carry-over of surface defects in the ingot to the extruded product. Preheating conditions are less stringent than for the rolled product. Control of discard is important and a minimum discard of around 15-20% is desirable, otherwise there is a danger of oxide folds and other back-end defects being revealed on anodising.

Demands are likely to be more exacting for high surface quality, since polishing costs are likely to be an important factor when extrusions are used: deep die lines are likely to prove expensive to the customer to eliminate, so that not only does the standard of finish required on the dies need to be of a high order, but subsequent techniques also require refinement. Careful filtration and circulation of drawing lubricants is important, as well as cleanliness of mandrels and other tools used in drawing.

Extrusions in HE9 and HE10 (magnesium-silicon) alloys are already in demand for semi-bright, matt or colour anodised finishes. It is well known that with these alloys, without manganese, a coarse grained outer band may be present. If extrusion conditions are not controlled to avoid this, a defect similar to "reticulation" will be found on the anodised section. The magnesium-silicon alloys containing manganese, with their higher recrystallisation temperatures, have greater freedom from this defect.

Heat treatment of these alloys may also have an effect on their response to anodising. The alloy HE10—1% silicon, 0.6% magnesium (nominal)—may give a brown-to-grey tint on anodising if the silicon:magnesium ratio is higher than the nominal. In any case the alloy has some excess silicon, and solution heat treatment at 540°–545° C., or even higher, will give a material with better response to anodising, whilst lowering the ageing temperature to around 130°–140° C. instead of the normal 160°–175° C. also helps with the fully heat treated temper, since this produces a finer distribution of precipitated particles and reduces their effect on the appearance of the anodic film.

Welding of extruded sections in HE10 material can also produce a discoloured zone adjacent to the heat affected zone around the weld. This can be reduced by choice of welding conditions so that the heat affected zone is reduced to a minimum. The welding rod should be of similar composition, or else an aluminium-5% magnesium alloy which reduces trouble from weld cracking.

Apart from surface quality, one of the main factors to be controlled in the production of super-purity base extrusions is the amount of cold work introduced in straightening if the section is required in the annealed temper. The amount of stretch required may be such as to introduce a critical amount of cold work, which will give a large grain size on annealing. Similar considerations apply to cold reduction of tubes by drawing.

Production of Hot Stampings and Pressings

The choice of stock for forging is always important, but bright anodising introduces new factors. For many applications cast stock has been favoured, since it permits closer control over grain flow than does the use of extruded stock, although more careful dummyming is required and press forging is usually employed. This is a slow and relatively costly method of production, so that any possibility of using hot stampings in the mass production industries will depend upon the ability of the forge to produce stampings rapidly and economically.

The most probable solution lies in the use of extruded stock, so as to eliminate some of the preliminary operations, and the adaptation of the type of equipment normally used in hot brass pressing to aluminium technique. This would probably involve the use of conventional drop hammers, but with increased tup weight. For many components a two stage die coining and finishing may prove adequate.

There are, however, additional points to be noted apart from modifications to equipment. Since polishing costs are high, customers will tend to demand high surface quality, which will demand a high standard of the finish and maintenance. Care will also be necessary to avoid the use of excessive lubricant, particularly of the type likely to give heavy carbonaceous deposits, since carbon particles may become entrapped in

the surface and give rise to pitting in subsequent cleaning and anodising operations. Greater care than usual may be required in the handling of these components to minimise possible surface bruises.

Production of Castings

At present the automobile industry is a large consumer of nickel-chromium plated zinc-base pressure die castings. It is obvious that attention should be paid to the possibility of producing pressure die castings in aluminium which will respond satisfactorily to bright anodising, since this is a parallel development to that of bright anodised roll-formed sections.

Pressure Die Castings

The production of such castings makes very exacting demands upon the foundry, and so far only slight progress has been made. In the first place the choice of alloy is limited by the considerations discussed in Section II. The foundry is therefore limited to the aluminium-magnesium or possibly the aluminium-magnesium-zinc alloys, whose casting characteristics are inferior to the commonly used aluminium-copper-silicon and aluminium-silicon alloys.

The author has been responsible for some experiments made in an attempt to produce pressure die castings with satisfactory bright anodising characteristics. Castings were made on a conventional small capacity horizontal cold chamber machine using ingot of 99.6% purity. The components were in the shape of discs of approximately 2½ in. diameter, with a central hole of about ⅜ in. diameter, and with two opposed lugs, approximately ⅝ × ¼ × ⅜ in., on one face: the casting temperature used was 685° C. Although the castings responded satisfactorily (for their purity) to chemical brightening and anodising, there were a few random flow lines which were associated with an oxide film included in the metal surface.

A second experiment was made with a similar machine, but the component produced was a handle, about 3½ in. long, of oval section ⅝ × ¼ in., but tapering away at one end. The die joint lay down the centre of the flatter portion and not down its natural parting line. The alloy used was a 1½% magnesium alloy based on ingot of 99.5% (minimum) purity. There was appreciable flash on this component, which may have been the reason why the castings were free from flow lines and gave a satisfactory response to chemical brightening and anodising.

Since in both of these experiments the hot strength of components seemed low, although the magnesium addition gave some improvement, it was decided to try a super-purity based aluminium-7% magnesium alloy which might be expected to have better casting characteristics. Once again a handle shape was used, but the previous die was not available. This handle was in fact a car door handle as at present produced in a zinc-base alloy. Whilst the casting characteristics appeared reasonably satisfactory (although this alloy has a tendency to dross readily) and it polished satisfactorily, the results of brightening and anodising were quite unsatisfactory. This seemed to be mainly due to the presence of numerous small surface flow-lines, although there was some etching which may have been due to lack of uniformity of magnesium content in the heavier sections.

It seems therefore that it should be possible to produce

small pressure die castings with satisfactory anodising characteristics, providing that attention is given to design of gating and generous provision of overflow wells to take out any entrapped air. From the anodising aspect, low magnesium contents would be desirable, but more work is required to establish the optimum level. The use of super-purity metal in the foundry would present big problems in the way of cleanliness and avoidance of contamination, as well as scrap segregation. From a production viewpoint a lower purity level would be desirable.

Gravity Die Castings

A few experiments have also been made with casting small flat plates $5 \times 2 \times \frac{1}{4}$ in. in aluminium of 99.8% and 99.99% purity and 4% magnesium alloys based on this purity of ingot. The pure aluminium gave satisfactory results, although there was evidence of porosity in the castings and of slight preferential attack around the iron-silicon constituents.

With the magnesium-containing alloys the surface was found to be rather mottled after anodising, but heat treatment for 6 hours at 435°C. largely, but not completely, removed this. A few experiments were also made with a gravity die-cast cable lug in normal purity ingot and this responded well to chemical brightening in a phosphoric brightener, but Brytal treatment seemed to give slight preferential attack at the grain boundaries. Slush cast tea-pot spouts have responded satisfactorily to Ertwerk brightening and anodising, provided the purity is maintained around 99.95%.

Sand Castings

Production of sand castings to give satisfactory response to brightening and anodising is unlikely to be easily achieved, since they are inherently coarse grained, compared with other materials, and liable to some degree of porosity. However, the author has made some initial experiments in casting 99.99% aluminium into plaster moulds using the wax investment technique. Small decorative motifs used for necklaces and other jewellery were used as patterns, and these responded very satisfactorily to phosphoric brightening and anodising without other preparation. Undoubtedly the high surface quality and the absence of any appreciable flat on the items helped in producing a good result, but the technique is obviously worth developing for this specialised field.

DISCUSSION AND SUMMARY

In the preceding sections it has been possible to state the basic principles governing the response of aluminium of varying purity and of aluminium alloys to brightening and anodising. To produce a bright finish comparable with that usually associated with chromium plate, the material must be homogeneous, so that this effectively restricts the choice to 99.99% aluminium and solid solution alloys based on this purity. For other less exacting applications, where merely an attractive finish is required, metal of 99.5%-99.7% purity is appropriate.

In the case of alloys, the fact that the alloying element is in solid solution does not ensure a bright finish after a suitable brightening operation and anodising. To obtain this it is necessary to select an alloying element whose oxide has a refractive index close to that of aluminium oxide, and which is colourless. Magnesium most closely approaches aluminium in this respect and has the advantage of having a wide solid solution range, thus

enabling alloys to be produced with a range of mechanical properties. Silicon also has the property of producing an oxide whose refractive index is close to that of aluminium, but this element has only limited solid solubility, particularly at room temperature, and gives only a small increase in strength.

However, there seems good reason to explore more fully the bright anodising properties of heat treated aluminium-magnesium-silicon alloys, which should be satisfactory for extrusions, since a higher extrusion rate would be expected than with aluminium-magnesium alloys. Some work has been done by one company (British Aluminium Co., Ltd.) who have an alloy based on small amounts of magnesium, silicon and copper, but this has had only limited use.

Where bright finishes are not required there are some interesting possibilities of obtaining special effects by control of composition. For example, a more dense opaque anodic coating should be possible on an alloy containing upwards of 1% zinc, due to the opacity of its oxide. Where solidity of colour is important, such as in architectural applications, an aluminium-zinc or aluminium-zinc-magnesium alloy would be expected to have superior characteristics to normal purity aluminium on account of the greater opacity of the anodic film. One possible approach is to clad the normal 14% manganese alloy with an aluminium-zinc alloy.

The merit of such a material is that it would tend to minimize the incidence of small defects, such as streaks, appearing in rolling; since the anodic film would tend to reflect light from itself and not from the metal surface. A further advantage from the customer's viewpoint is that the higher anodising rate would enable process time to be reduced, and that the appearance of the dyed film might be considered more attractive than that obtained with commercial aluminium or the common alloys.

The general principles established in Section II regarding the influence of composition on response to brightening and anodising have been further confirmed and extended in Section III, which has been primarily concerned with metallurgical factors. It has been shown that for bright anodised finishes metallurgical control and production technique must be of a very high order. Not only has the composition of the material to be one which will give a solid solution, but the solid solution must be homogeneous, since even small differences in composition will adversely affect the response to brightening and anodising. For applications where a bright finish is not required, the metallurgical standards are less exacting but, even so, the presence of a second phase will adversely affect the response to anodising, in that it tends to give a mottled and often non-uniform appearance to the product, as well as lowering the efficiency of the anodising process and thus increasing cost.

Considering the problems of producing bright anodised material, it is evident that any large demand for sheet and strip in the mass production industries would present problems to the aluminium fabricating industry. Since grain refining elements reduce the brightness after anodising, they are unsuitable for ingot grain size control on super-purity base materials; this means that casting conditions must be carefully watched. Whilst pre-extrusion of the ingot gives a first class product, it limits the size of slab which can be handled on the hot mill.

A heavy reduction of slab thickness is essential and this can present problems in the thicker gauges. It is

suggested that cladding with material previously hot rolled or pre-extruded strip may provide the solution to the problem. During hot rolling, surface defects associated with mill pick-up often occur, and pickling of the hot mill strip prior to cold rolling is most desirable. This is a further difficulty and it is suggested that a continuous pickling plant may have to be developed, in which case a rapid acting pickling solution would be desirable, and the use of the Erftwerk brightening solution for this purpose might be investigated. For other anodising applications, such as colour-anodised sheet for cladding of buildings, requirements are less exacting, although even here streaks associated with hot mill pick-up or other rolled-in dirt could still be objectionable.

Production of extrusions and tubes offers fewer difficulties than sheet, although again some precautions such as control of discard and of grain size, are necessary. In view of the importance of a high finish to the customer, more emphasis is likely to be placed on the ease of polishing the extruded section as received. This will stimulate research on the problem of lubrication of extrusion dies. Hot stampings can also be bright anodised, but any large scale demand for these would involve development of equipment suitable for high production rates.

Castings present a problem that is not yet solved, although certain lines of approach suggest themselves from work already carried out. In the first place there would appear to be little difficulty in producing castings in pure aluminium. Small precision (plaster mould) castings have been made without difficulty in 99.99% purity metal, and provided the components are small and the sections not heavy this technique should be capable of commercial development. The purity of the metal should be kept as high as possible, since large particles of aluminium-iron-silicon constituents will probably adversely affect the response to finishing. Similarly, slush castings or small gravity die castings should also prove quite satisfactory.

The technique of producing castings by the above methods in an alloy having satisfactory characteristics may be a little more difficult, but with any of the methods described above aluminium-magnesium alloys seem to offer the only possible choice. It will be necessary to keep the magnesium content as low as possible, and it is also certain that a homogenising heat treatment will be required.

Pressure die casting presents great problems, but also great possibilities. The process gives a very fine grain, which is advantageous, but the difficulty with die casting is the tendency for injection to produce turbulence and entrapped oxide. Provided that careful attention is paid to gating, and generous overflow wells are suitably located, it may well prove possible to produce small castings of suitable design which will brighten and anodise. However, it should prove easier to produce castings with a matt anodic finish than with a bright finish.

REFERENCES

- 1 Bruce, A. W., *Metal Finishing Journal*, 1955, **1** (6), 255-8, 278; (7), 310-323, 327.
- 2 British Patent 449,162.
- 3 British Patent 453,484.
- 4 British Patent 645,453.
- 5 British Patent 612,478.
- 6 Bruce, A. W. and de Gromoboy, T. S., "Some Studies of the Behaviour of Phosphoric Acid Base Brightening Mixtures for Aluminium." Aluminium Development Association T.M.281.
- 7 British Patent 687,774.
- 8 *Light Metals*, 1954, **15** (200), 348-349.
- 9 U.S. Patents 2,513,447; 2,513,448; 2,593,449; 2,620,265.
- 10 U.S. Patent 2,614,913.
- 11 British Patents 693,776, 693,876 and 738,711.
- 12 Fisher, N. D., *J. Inst. Metals*, 1936, **59**, 151-158.

- 13 Edwards, J., *J. Electrodeposits Tech. Soc.*, 1951/2, **28**, 133-148.
- 14 Hunter, M. S. and Fowle, P. J., *Electrochem. Soc.*, 1954, **101** (9), 481-485.
- 15 Fischer, A. and Koch, L., *Metall*, 1952, **6** (17/18), 491-496.
- 16 Koch, L. and Keste, S., *Metall*, 1953, **7** (15/16), 577-581.
- 17 Helling, W. and Neunzig, H., *Aluminium*, 1952, **28** (9), 289-295.
- 18 Handbook of Chemistry and Physics, 1954-5, 36th Edition, 1473-1475, 2664-2668.
- 19 Fischer, H., Budiloff, N. and Koch, L., *Korr. u. Metallsch.*, 1940, **16** (7/8), 236-246.
- 20 Fischer, H., Budiloff, N. and Koch, L., *Wiss. Veröff. Siemens-Werken, Werkstoff Sonderheft*, 1940, 169-187.
- 21 Lacombe, P. and Morize, P., "Etudes sur les Aspects des Pellicules d'Oxydation Anodique Formées sur l'Aluminium et de ses Alliages," p. 33-42.
- 22 Lacombe, P. and Beauviard, L., *Ibid.*, p. 59-72.
- 23 Herenguel, J., *Metall, Corrosion-Cause*, 1945, **20** (238), 77/82.
- 24 Herenguel, J. and Segond, R., *Metall et Corrosion*, 1949, **48**, 377.
- 25 Herenguel, J., "Etudes sur les Aspects des Pellicules d'Oxydation Anodique Formées sur Aluminium et de ses Alliages," p. 43-56.
- 26 Herenguel, J. and Scheidicker, M., *Metall et Corrosion*, 1948 (275/6), 167-174.
- 27 Straumeris, M. E. and Wang, Y. M., *J. Electrochem. Soc.*, 1955, **102** (7), 382-386.

British Nuclear Energy Conference

At a meeting of the Board on January 9th, 1957, the Iron and Steel Institute and the Institute of Metals were elected members of the British Nuclear Energy Conference. It had been felt for some time that the Conference would be strengthened by the inclusion of representatives of metallurgy, and the election of the two Institutes to membership will be welcomed by the metallurgical profession.

The object of the Conference is to co-ordinate the activities of the constituent societies in the field of nuclear energy by holding meetings and publishing a journal. Members of the constituent societies are entitled to attend meetings sponsored not only by the British Nuclear Energy Conference, but also those arranged by any of the constituent societies, and details of these meetings will be announced from time to time in the Journals of the Iron and Steel Institute and of the Institute of Metals. Members of the constituent societies are entitled to purchase the quarterly Journal of the Conference at the reduced annual subscription rate of 30s.

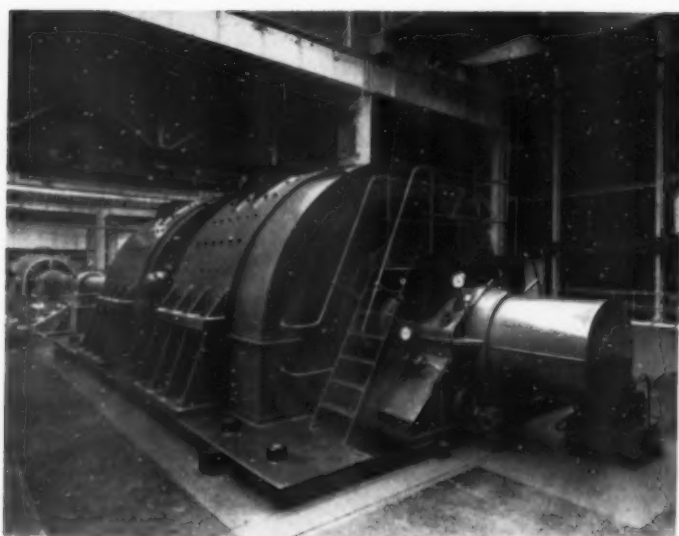
Corrosion Lecture

THE Spring Lecture of the Corrosion Group of the Society of Chemical Industry will be delivered on Monday, April 8th, 1957, at 6.30 p.m., at the Society of Chemical Industry Headquarters, 14, Belgrave Square, London, S.W.1, when PROF. R. PIONTELLI (Head of the Electrochemical Laboratories of the Polytechnic Institute of Milan) will lecture on "Recent Research at Milan on the Electrochemistry of Corrosion."

Professor Pontelli will describe the researches carried out by himself and his co-workers on the behaviour of metal electrodes and its relation to corrosion and electroplating. The distribution of current in electrochemical systems, passivity and metal replacement reactions will be discussed, and research on the behaviour of single crystals will be described.

Old Engravings

J. H. VILLARD, Inc., of 175, Fifth Avenue, New York 10, N.Y., have assembled an important collection of old engravings, mostly of the 18th century, featuring scenes of the metal industries, depicting such operations as smelting, refining, rolling, fabricating, etc. Some of the pictures are for sale, or can be rented for publicity purposes. The collection can be seen by appointment, and correspondence is invited from collectors who have duplicates to exchange.



Courtesy of English Electric Co., Ltd.
0/7000/7000 h.p., 0/40/80 r.p.m. double armature reversing mill motor driving a 42 in. slabbing mill at John Summers & Sons, Ltd.

Electrical Plant for the Metal Industries

Progress in 1956 Reported

(Continued from the March issue).

THE electrical industry continues to play a major part in the provision of equipment for the metal industries. Electrical drives for rolling mills—whether as new construction or for the modernisation of existing mills—undoubtedly constitute one of the outstanding applications of electricity in this field, but a considerable volume of business concerns the smaller motors, switchgear, rectifiers, and, more recently, electronic control equipment. The following information, based on surveys of the activities of a number of the large electrical engineering concerns in 1956, will give some idea of the extent to which metal working depends on electricity. The review is not exhaustive, and is confined mainly to equipment used in the manufacture of semi-finished products.

English Electric Co. Ltd.

Rolling Mills

Equipment put into commission during the year, together with orders received, made 1956 another successful year for the Metal Industries Division, and, taking into account work put in hand but not commissioned, it was also an extremely busy year.

Among the large hot mill drives commissioned was that for the 40 in. blooming mill at the Stocksbridge Works of Samuel Fox & Co., Ltd. This comprises a 5,000 h.p. (r.m.s.) reversing mill motor fed from an Ilgner set consisting of a 4,000 h.p. A.C. motor and a flywheel with a stored energy of 150,000 h.p. sec. driving three generators of 1,340 kW. each.

For the 42 in. slabbing mill at John Summers & Sons, Ltd., a 7,000 h.p. (r.m.s.) reversing mill motor drive with double armature has been supplied. The motor is supplied from an Ilgner set comprising four 1,420 kW. generators, driven by a 5,500 h.p. A.C. motor and a flywheel having a stored energy of 200,000 h.p. sec. An interesting feature of this drive is the 48 ft. long jack

shaft transmitting the drive from the motor room to the mill via the room housing the old steam engine drive.

In the two structural mill drives commissioned at Workington Iron and Steel, the two reversing mill motors are fed from one Ilgner set. The main drive motors are of 2,750 h.p. for the roughing mill and 2,500 h.p. for the finishing mill, whilst the Ilgner set comprises four generators of 1,100 kW. each, driven by a 5,000 h.p. slipring motor and a flywheel having a stored energy of 150,000 h.p. sec.

An intermediate mill drive on the South Durham 90 in. plate mill was also put into operation, the reversing mill motor being of 2,650 h.p. (r.m.s.). For reversing mill duties, the mill motors are designed for a peak (cut-out) torque which is three times the r.m.s. value.

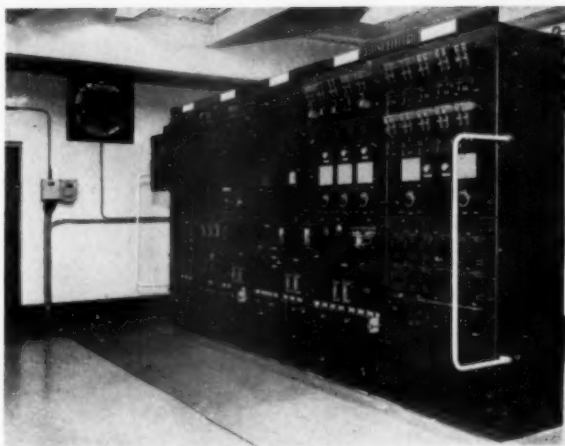
Following on the starting-up of the 5-stand cold mill drive for the Ebbw Vale Works of Richard Thomas & Baldwins, Ltd., in 1955, there has been commissioned at the same works a 2-stand temper mill drive. This mill is one of the most modern of its type in Europe, and is capable of rolling 38 in. wide strip at speeds up to 4,500 ft./min. The main drives each have 1,000 h.p. motors, and 300 h.p. motors drive the reels, which have 20 in. coiling drums capable of carrying 30,000 lb. coils.

A number of single stand cold mills with tension reels were commissioned during the year, including equipment for I.C.I. Metals Division, Bruntons (Musselburgh) Ltd., and Steel, Peech & Tozer. The I.C.I. single stand non-reversing cold mill has a 1,300 h.p. mill motor and 400 h.p. double armature reel motors.

Overseas equipment commissioned included a cold strip mill for British Tube Mills (Australia), Ltd., and orders received from overseas during the year were representative of many countries and continents, among them U.S.A., India, Spain and Brazil. The contracts covered a wide range of equipments, including blooming, billet and intermediate mills, bar and merchant mills, and continuous rod, bar and wire rod mills.

The outstanding overseas development was undoubtedly the order placed by the Indian Government with a group of British firms for the supply and erection of a complete steel works at Durgapur; the value of the equipment being supplied from this country is nearly £57 million. To handle this project, the firms concerned formed the Indian Steelworks Construction Company, so that each could handle its share in concord and in accordance with the overall plan. The English Electric share includes the drives and associated auxiliary motors and control gear for the intermediate reversing mill and continuous billet mill, together with transformers, H.T. and L.T. switchgear, fusegear, rectifiers and traction equipment.

The continued development of the Steel Company of Wales has produced a new project with a view to stepping up the production of the 45 in. slabbing mill by the addition of a 37 in. vertical close coupled edger. With the vertical edger in operation, although the ingot still has to be turned once, or possibly twice, for initial edging in the main stand, edging is accomplished in the same pass as rolling, thereby reducing the total number of passes and the manipulation time. This saving of time will, it is expected, enable the output to be raised to an average of 60,000 tons weekly. English Electric have received the orders for both the 4,000 h.p. edger drive, with its synchronous motor generator set, and additional auxiliary drives which include the feed rolls, edger roll adjustment, manipulator fingers and a new shuttle car to ply between the ingot buggy and the mill entry table. The introduction of the shuttle car is necessitated by the rapidity with which slabs can be put through the mill with the vertical edger in operation. Relying on the ingot buggy alone to collect and deliver the ingots would lead to the mill being starved.



Courtesy of English Electric Co., Ltd.

Part of the controls for the drive of a two-stand tandem temper mill at Richard Thomas & Baldwins, Ltd.

A range of orders has been received from the home market for main drives and auxiliary motors, together with distribution switchgear and transformers for projects such as a 21-stand rod and bar mill with four edger stands; merchant, rod and bar mills for steel and copper; a 40 in. blooming and slabbing mill; a four-high plate mill; and a 13 in. Sendzimir mill complete with tension coilers.

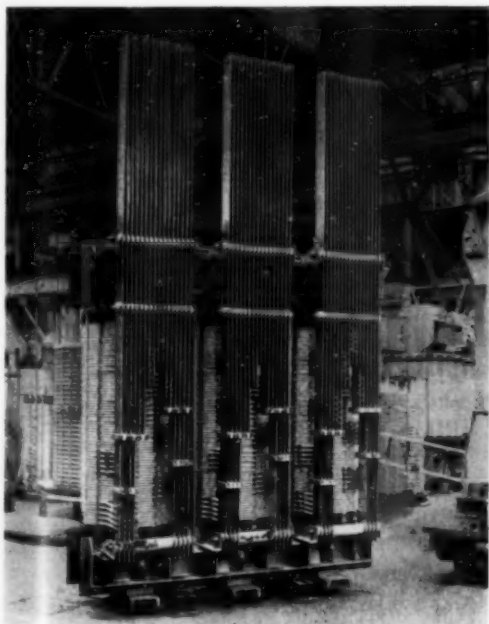
Furnace Transformers

The increasing activity in arc-furnace transformer business was well maintained during the year. Among interesting contracts were three 20 MVA. and three 12.5 MVA. installations for this country, and a 10 MVA. unit for South Africa. One 20 MVA. transformer will supply an 80-ton furnace at the Stocksbridge Works of Samuel Fox and Co., Ltd., and the other two will be installed at Round Oak Steel Works for 60-ton furnaces. The 12.5 MVA. units are for 40-ton furnaces at Brymbo Steel Works, near Wrexham. All these transformers are provided with English Electric on-load tap-changing equipment, by means of which the furnace voltage can be varied as required without interrupting the melting or refining process. The Samuel Fox unit is designed for a 66 kV. supply, and the others for 33 kV., and all are provided with auxiliary windings for connection to static condensers for power factor improvement. The 10 MVA. furnace transformer is designed for an 11 kV. supply, and will feed a 30-ton furnace. On this unit, control of the furnace voltage is by a motor operated off-circuit tapping switch, and the supply circuit breaker must be opened before the voltage can be changed.

Miscellaneous

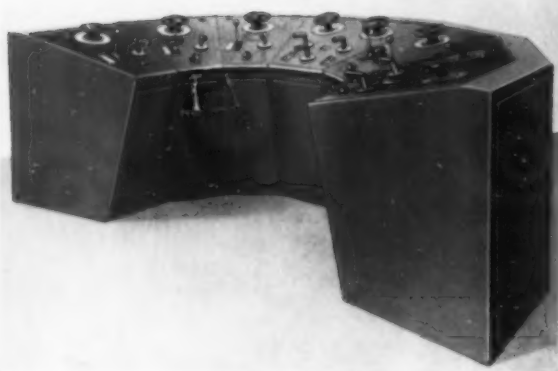
Electronic Control.—During the year, standard magnetic amplifiers for 50 c./s. and 400 c./s. supplies, and for outputs from 150 to 1,500 watts have been used on a number of auxiliary drives in steel mills. They have been incorporated in the control units of several major schemes, e.g., in the drives for flying shears, roughing and finishing mills, galvanising lines, the reflow of tinplate, etc.

Mercury-Arc Rectifiers.—The increasing application of sealed air-cooled steel-tank mercury-arc rectifiers for



Courtesy of English Electric Co., Ltd.

Core and windings of a 15 MVA. 11 kV. three-phase arc furnace transformer.



Courtesy of Metropolitan-Vickers Electrical Co., Ltd.

Operator's desk for a two-stand rod mill at Templeborough Rolling Mills.

supplying power to rolling mill motors is shown by the orders received during 1956. Equipments up to 3,500 kW. each have been ordered for a billet mill and for three rod and bar mills, grid control being used in every case for starting and motor speed control. Orders for mill auxiliary rectifiers include one totalling 11,650 kW. for a new steelworks to be erected in India. Repeat orders were received from a number of home and overseas steel mills.

Hydro-electric Alternator.—A repeat order has been received from the Aluminium Company of Canada for a second alternator for the Kemano power house. This machine is rated at 132,000 kVA., 13.8 kV., 60 c./s., 327 r.p.m.

Metropolitan-Vickers Electrical Co., Ltd.

Rolling Mills

A large twin-drive blooming mill equipment shipped to the Cleveland Works of Dorman Long comprises two 2,500 h.p. 40/90 r.p.m. D.C. motors with associated flywheel motor generator set and control gear. Equipment for a universal broad-flange beam mill for the same company's Lackenby Works in course of shipping forms part of a joint contract with B.T.H. which covers three 8,000 h.p. 65/100 r.p.m. motors for the main drives, and two twin-motor drives comprising 1,350 h.p. 125/310 r.p.m. motors, together with the associated motor generator sets and control gear.

D.C. electric drives are in hand for two mills for rolling aluminium foil up to 34 in. wide at speeds up to 3,000 ft./min. Each mill comprises a single roll stand with uncoiling and coiling reels, and will be equipped with a 350 h.p. 1,225 r.p.m. mill drive and a 24 h.p. 600/1,500 r.p.m. motor on each reel. The motors are supplied from individual generators with Ward-Leonard control, a 450 h.p. four-machine motor generator set being provided for each mill. Constant tension control and mill speed control are by means of flux-resetting magnetic amplifiers. The mill speed control is arranged to run the mill up to speed on acceleration limit in about 10 seconds.

Two identical hot reversing mill drives to be commissioned in 1957 at the Stocksbridge Works of Samuel Fox will have a combined weekly output of 10,000 tons,

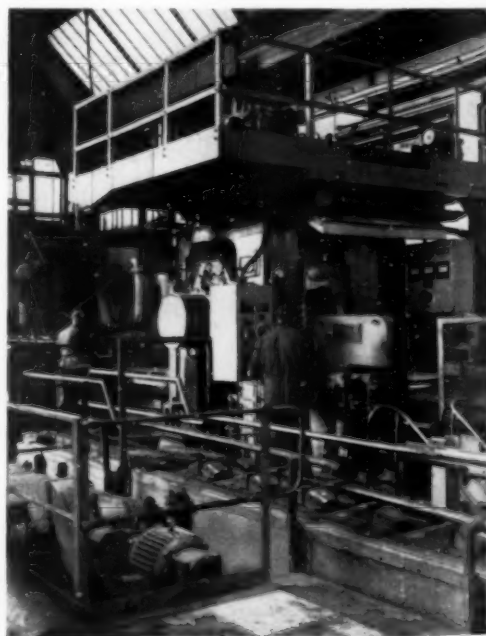
rolling billets and round bars, respectively. The equipments will incorporate 60/150 r.p.m. D.C. motors with a rating of 4,000 h.p. r.m.s. (12,000 h.p. peak), each motor being supplied from two 1,600 kW. generators driven by a 4,800 h.p. synchronous motor.

A large main drive has also been ordered for a new four-high reversing hot mill for the Appleby-Frodingham Works of United Steel Companies, which will be capable of rolling plates up to 65 ft. long and 12 ft. wide, the minimum thickness being $\frac{3}{16}$ in. and the maximum slab weight 25,000 lb. It will be driven by twin 4,000 h.p. 40/100 r.p.m. D.C. motors having a maximum total output of 24,000 h.p.; these will be supplied from a 6,400 kW. (19,200 kW. peak) flywheel motor generator set, and the standard amplidyne control scheme will be employed, incorporating load and speed balance and automatic load limitation.

An interesting equipment has been ordered for a cold strip mill to roll aluminium and its alloys. The main drive will be provided by two 900 h.p. 500/1,060 r.p.m. D.C. motors, and the reel drive is rated at 1,050 h.p. 500/1,250 r.p.m. Flux-resetting magnetic amplifiers are being used on the reel motor and generator for the tension control scheme, and overriding tension meter control will be fitted later on to feed into these servo systems.

Among rolling mills being modified or reconstructed is the 30 in. intermediate reversing mill at Steel, Peech & Tozer which M-V equipped in 1930. A larger driving motor (2,200 h.p.) has been installed for the motor generator set together with new switch and control gear, and this will be followed by a new 1,275 h.p. motor generator set for the Ward-Leonard auxiliary drives together with control gear and several MDX mill motors.

A 40-in. blooming mill at the Corby Works of Stewarts



Courtesy of Metropolitan-Vickers Electrical Co., Ltd.

A strip mill driven by an 800 h.p., 500/1000 r.p.m. D.C. motor supplied by mercury arc rectifiers at the Witton Works of I.C.I. Metals

and Lloyds is being modified to a 48 in. mill, retaining the original main motor; it will be equipped with a new flywheel motor generator set and control gear. The auxiliary drives are also being modified, and to enable the screwdowns to operate at still higher speeds, means are to be provided for presetting the screws automatically.

Other modifications include the renovation of a 1,500 h.p. roughing mill motor and a 2,500 h.p. finishing mill motor installed at Whitehead Iron and Steel, Newport, where they have given satisfactory and continuous service since 1920.

Electrical equipment has been ordered by Dorman Long for a Morgan flying shear, which will cut slabs up to 2×12 in. at 225 ft./min. and billets from 2 in. to 3½ in. at speeds up to 465 ft./min. The lengths to be cut will range from 12 ft. to 31 ft., and the machine will operate either as a start-stop shear or a speed-up slow-down shear, depending on the length to be cut. To ensure accuracy, the cutting cycle will be initiated by means of photo-electric cells that are sensitive to the infra-red rays from metals at dull cherry-red heat. A metadyne will excite the generator supplying the driving motors, and a very high degree of field forcing will accelerate them up to cutting speed. The shear is driven by two 150 h.p. mill type motors, and the whole equipment will be duplicated in due course.

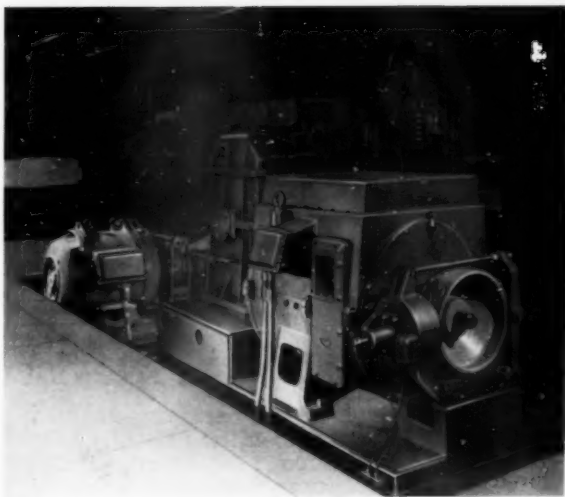
Three 3-stand wire-flattening mill equipments have been ordered; one, a duplicate of equipment supplied in 1954, is to be installed at Greenwich, and the other two in the Birmingham area.

Process Lines

A number of process lines have been put into service during the year, or will shortly be commissioned. A pickle line at Richard Thomas & Baldwins dealing with steel strip up to 54 in. width and 0.145 in. thickness, is divided electrically into three groups, each with a generator supplying a D.C. motor. The D.C. motors total 1,200 h.p. and the A.C. motors nearly 400 h.p. Looping at each end of a group allows the strip to be sheared, welded and stitched without stopping the strip in the tanks; photoelectric control in the looping pit at the exit keeps the size of the loop constant when the line is running normally.

Two electrolytic cleaning lines at the Velindre works of the Steel Company of Wales have been commissioned. Each of these lines has a 100 kW. uncoiler motor, thirty 4½ h.p. geared motors for the tank group, two tension bridle-roll motors, and a 300 h.p. 300 r.p.m. coiler motor; all these machines will be supplied from a single 300 kW. 300 V. generator. They are the first of their type in this country with "tight strip" right through, previous cleaning and pickle lines having had loops in the strip with photocells controlling the height of the catenary. The new equipments incorporate straight-forward Ward-Leonard control for the tank group and tension bridle motors, and the M-V standard tension-control scheme for the uncoiler and coiler; boosters are used for IR drop compensation.

A 54 in. cut-up line for the Abbey Works of the Steel Company of Wales is now in commission, handling material at 700 ft./min. A 64 in. pickle line equipment in the same works has been modified and is working satisfactorily. A 12 in. softening and descaling line to be supplied in the Sheffield area will have a control



Courtesy of Metropolitan-Vickers Electrical Co., Ltd.

A pickle line at the Abbey Works of the Steel Company of Wales: a 250 h.p., 1,140/1,320 r.p.m. type Q totally-enclosed closed-air-circuit squirrel cage motor with single radiator driving pinch rolls, and (at back) a 50 h.p. R.S. motor driving an up-cut shear.

scheme similar to another commissioned during the year in the same area.

Miscellaneous

Auxiliary Drives.—Ninety-five A.C. and D.C. motors ranging from 7½ h.p. to 350 h.p. are in hand for driving Wellman and Carruthers cranes and Loewy Engineering mill equipment at the Patent Shaft and Axletree works. Among MDX motors ordered for crane and mill drives are 32 for Steel, Peech & Tozer. A total of 181 motors, ranging from 7½ to 200 h.p. are in hand for Colvilles, mainly further equipment for the Ravenscraig scheme. Seven additional motors ranging from 15 to 150 h.p. have been ordered by Wellman Smith Owen Engineering for cranes required by the Société-Metallurgique de Normandie, to replace equipment damaged during the war. Among overseas contracts, six more type Q D.C. motors of 50–75 h.p. have been ordered by Martin Burn for driving pipe spinning machines in a new extension to the Kulti Works of Indian Iron and Steel.

Drawbenches.—A new drawbench installed near Glasgow is rated for 100,000 lb. pull, and has been equipped with a 450/300 h.p. slipping motor main drive and all electrical auxiliaries. Another drawbench being erected in Leeds has a 500 h.p. D.C. variable speed motor for the main drive, together with all auxiliaries and a special rotary back-bench drive; it is provided with fully automatic as well as manual control. A scheme has been developed for equipping a variable frequency wire drawing machine using standard squirrel cage motors.

Vacuum Furnace.—A 1 ton induction heated vacuum furnace to operate at pressures from 10 to 50 microns (McLeod gauge) is in course of development. Such a furnace must be capable of continuous operation, with provision for making alloy additions, pouring and mould removal and replacement whilst the vessel is at low pressure; the new plant will consist of a furnace chamber and a mould chamber connected by an isolating

valve, the furnace chamber containing the entire melting equipment, including hydraulic tilting and other auxiliary units.

H.F. Generators.—A newly developed range of high frequency motor generator sets, type HE, will give 100–300 kW. at 1,650 and 2,250 c./s. or 100–200 kW. at 10,000 c./s. The generator is driven by a squirrel cage motor assembled in the same enclosure, the rotors being mounted on a common shaft; the ball and roller bearings have constant-level oil lubrication. A high efficiency blower mounted between the generator and motor cores draws separate streams of cooling air axially

through the cores, discharging it at the centre into either a sound absorbing chamber (drip-proof machines) or an external water cooled radiator circuit (totally enclosed air-circuit motors).

Blast Furnace Equipment.—A 125 h.p. blast furnace hoist will have a skip motor supplied by a 105 kW. Ward-Leonard generator with a 24 in. solenoid-operated brake acting on the winder drum. Other orders concerned with blast furnace raw materials handling include equipment for three 50-ton Head Wrightson transfer cars—a scale car for South Durham Steel & Iron, and two sinter cars for Dorman Long.

New and Revised British Standards

UNIVERSAL DECIMAL CLASSIFICATION—ABRIDGED
ENGLISH EDITION
(B.S. 1000A : 1957). PRICE £2 2s. (BOUND) AND £1 15s.
(UNBOUND).

THIS is a completely revised edition of the abridged schedules (with introduction and alphabetical index) published by the British Standards Institution in 1948. It presents several important new features which should commend themselves to the steadily increasing number of library and other classifiers who depend on B.S.1000A as the only complete English edition of the U.D.C. at present available.

The edition is bound in cloth-covered stiff boards, with coloured dividers (for quick reference) between the three main sections—Introduction, Tables, and Alphabetical index. Preceding the General Introduction, there is a new Note on the Dewey D.C. and U.D.C., explaining the resemblances and differences between these two related systems; and the General Introduction itself has been recast as a concise guide for the less experienced classifiers, and as the simplest possible explanation for the uninitiated and curious. Equally important is the freshly compiled Alphabetical Subject Index, which now runs to well over 20,000 entries, as against some 2,000 in the 1948 edition.

In both the Main and Auxiliary Tables, the terminology has been extensively revised, and significant "Extensions and Corrections to the U.D.C." authorised to date have been incorporated. Though slightly extended, these abridged tables are still about one-tenth of the length of the full edition; they are therefore sufficiently detailed for most general use whilst providing the essential "background" for specialists to use in conjunction with any appropriate sections of the full edition already published as B.S. 1000, or available in French and/or German.

IRON AND STEEL FOR COLLIERY CAGE SUSPENSION
GEAR, TUB AND MINE CAR DRAWGEAR AND COUPLERS,
AND ROPE SOCKETS

PART 3: 1.5% MANGANESE STEEL CASTINGS
FOR MINE CAR COUPLERS.
(B.S. 2772 : 1957). PRICE 3s.

AUTHORISED by the Iron and Steel Industry Standards Committee, B.S. 2772, Part 3 is part of a general revision of British Standards for iron and steel for colliery haulage and winding equipment. It specifies the requirements of the mining industry in respect of 1.5% manganese steel castings for mine car couplers. The requirements for chemical composition and for mechani-

cal properties have been selected after careful consideration of the particular conditions to which the couplers will be subjected in service, and every precaution has been taken to ensure that couplers manufactured from this material will give the greatest possible protection to those employed in the mines. Appendices include the recommended dimensions for the standard preparation round tensile test piece and the procedure for welding.

STEEL LINKS AND STRAP ASSEMBLIES FOR LIFTING
ATTACHMENTS FOR PACKING CASES
(B.S. 2837 : 1957). PRICE 5s.

THIS new British Standard specifies requirements for the lifting straps and rings used on packing cases. Previously the source of guidance on this subject was Section 8 of the "Packaging Code" (B.S. 1133), but investigation has shown the need for a more precise specification. In consequence, the recommendations in the Packaging Code are being deleted, and this new publication will take their place.

The standard provides for seven classes of links and strap assemblies having a range of safe working loads from 4 cwt. to 5 tons. Some general guidance is also given on the methods of applying these assemblies to the packing case. Of special importance are the requirements for welding of the triangular links (rings). The standard recommends that the weld should be in one of the straight sloping parts of the link and not in any of the radii or in the lower straight part of the link. This recommendation has been made in order to avoid a welded joint occurring at a point of maximum stress. It is recognised, however, that it is a departure from current practice, and that it may be a little time before manufacturers of links are in a position to meet this requirement. It is hoped, however, that they will see their way to do so as soon as possible.

Copies of these British Standards can be obtained from the British Standards Institution, British Standards House, 2, Park Street, London, W.1.

Denison Area Sales Offices

Saml. Denison & Son, Ltd., makers of weighing and testing machines, of Leeds, have opened area sales offices in the north-west and north-east. The former is at King's House, 42, King Street West, Manchester, 3 (Tel: BLAckfriars 1989), and the latter at West Bar Chambers, 38a, Boar Lane, Leeds, 1 (Tel: Leeds 2-8433). The respective managers are Messrs. H. Hunt and S. A. Morris.

Britain's First Mains Frequency Coreless Induction Melting Furnace

Birlec Installation at International Combustion

THE first mains frequency coreless induction melting furnace to go into service as a production unit in this country was commissioned last month at the Derby works of International Combustion, Ltd., the well known power station and boiler house contractors and manufacturers of pulverised fuel plants. Of 5 tons capacity, the furnace will be used mainly as a holding and superheating unit for cupola metal in the production of special irons.

Features of Mains Frequency Melting

The basic principles of this type of furnace are the same as those of the better known high frequency induction furnace. The melting chamber or crucible, which is cylindrical in shape and lined with a rammed refractory, is surrounded by a helical water-cooled copper coil, through which a heavy current is passed to induce in the charge the current necessary to heat it. The furnace can be considered as a simple transformer, with the charge forming the secondary coil.

The mains frequency furnace has all the advantages of induction melting—complete control of metal composition and temperature—but operates at a frequency of 50 cycles per second. Other furnaces employing the

induction principle either require expensive equipment to convert mains frequency into high frequency (1,000–10,000 cycles per second), or employ a special core type of melting chamber, which in many foundry applications is less convenient and less reliable than the open crucible. Furthermore, in the core type of induction melting furnace, it is impracticable to attain the temperatures required for the melting of alloy irons and steels. The 50 cycle current induces a vigorous stirring action in the bath, ensuring that the whole depth of molten metal is at uniform temperature and of uniform analysis.

The mains frequency melting furnace became a practical proposition when it was appreciated that the charge must consist of comparatively large pieces—i.e. not less than 8 in. diameter for iron and steel. This requirement arises from the increased depth of penetration of the current in the charge, as compared with high frequency melting. The mains frequency can, however, be used for swarf recovery; large pieces are used for the initial melt and the swarf is added to the bath.

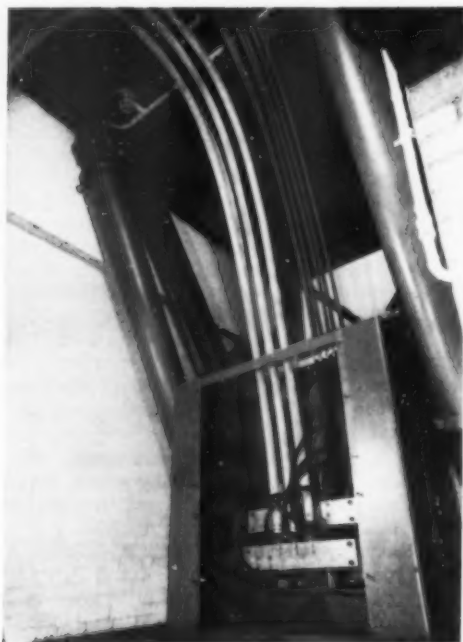
The makers of the unit installed at International Combustion—Birlec, Ltd.—have been interested in the mains frequency furnace for some years, and after long and intensive research a small experimental prototype was installed in July 1955 at the Coventry works of the British Piston Ring Co., Ltd., where it was successfully used for melting a range of ferrous and non-ferrous alloys. Later that year it was announced that Birlec, Ltd., had concluded an agreement with Otto Junker



Pouring the Birlec 5 ton mains frequency coreless induction furnace at International Combustion, Ltd.



Centre bay of the foundry, showing loam mould of large casting being poured. One of the two ladles used is shown pouring and the other is withdrawn at left centre.



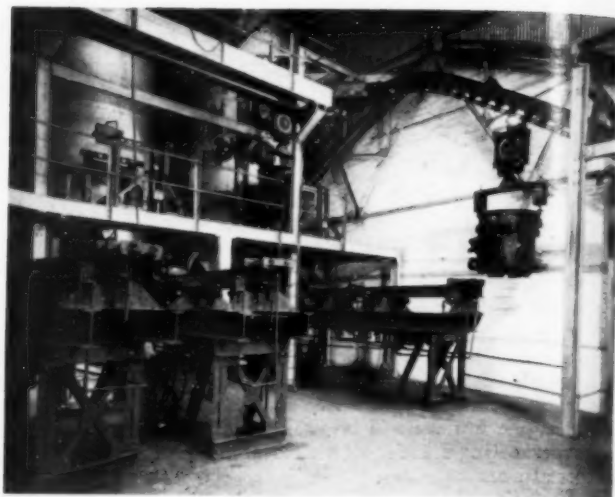
Inside the foundation pit, showing the furnace with the back plates removed: cables busbars, water pipes and hydraulic tilting rams can be clearly seen.

G.m.b.H., of Lammersdorf, Germany, and the Ajax Engineering Corporation, of America, for the development and marketing of this type of equipment, which had been pioneered over a number of years by Junker. This was followed by lectures given at various centres on design considerations and applications of the mains frequency coreless induction melting furnace which were reported in *METALLURGIA**. In October of last year a 5-ton holding furnace of this type was shipped to India for installation in the Jamshedpur foundry of the Tata Engineering and Locomotive Works, and now the first production unit in the country has been commissioned.

The mains frequency furnace is finding increasing application. Otto Junker have a considerable number in operation, and already Birlec have orders for fourteen installations for a wide variety of uses with both ferrous and non-ferrous metals, including: cast-iron—remelting borings; steel—swarf reclamation; aluminium—swarf and trimming reclamation; and bronzes and brasses—melting and swarf reclamation. The sizes of the furnaces on order vary from 12 cwt. to 15 tons, which will be amongst the largest induction melting furnaces in the world, of either H.F. or L.F. design.

International Combustion Installation

International Combustion, Ltd., have long been concerned in the production of high quality iron castings, including many of the heat resisting variety for incorporation in the various forms of combustion equipment which they manufacture. They also produce castings of specialised types for grinding, screening and filtering equipment which, in the chemical industry, for example, calls for a careful selection of materials. The early adoption of the mains frequency coreless induction



Cupola charging platform showing two of the four cupolas and a charging bucket with scale attached travelling up the overhead conveyor. In the foreground is the Lec gear for charging the cupolas.

furnace is in line with the company's progressive outlook. Two of its four cupolas are operated on the hot blast system, and the mechanised charging equipment designed by the company's engineers has several points of interest. Moreover, the mechanised casting plant was a very advanced installation at the time of its construction in 1924.

Applications

The new furnace will be concerned mainly with spheroidal graphite (S.G.) cast iron to be used in place of steel castings and complicated steel forgings which at present form components of pulverising mills, powdered fuel burners, coal feeders, travelling grate stokers, spreader stokers, and various components of grinding, screening and filtering plants. S.G. cast iron has already been used for prototype castings such as mill roller arms, stoker driving gear box worms, gear wheels of various sizes, grinding rolls and similar parts. The results, from the point of view of both production and prolonged wearing life, are extremely promising, and it is proposed to extend the application of this ductile iron to include every component where the form indicates a casting and the function indicates a high duty metal. The component parts selected for production in this way are already being redesigned to make the fullest use of the new casting technique, and there is no intention of merely changing the specification of the iron and using the same patterns and casting routine.

In the production of S.G. iron, the new furnace is intended to serve as a holding and superheating unit, being fed from cupolas. Such a unit is necessary for the production of high quality grey irons and S.G. iron, since they must be available at closely controlled temperatures. From both manufacturing and economic standpoints it is less satisfactory to produce these materials direct from a cupola, on account of poor quality coke and scrap and the high price of pig iron. Alloying elements can be added in the holding furnace—otherwise they would have to be added in the ladle immediately prior to casting, causing an unwanted drop in temperature; chiefly for safety reasons, magnesium

* *METALLURGIA* (1936) 88, 99-102, 171-174.

additions are in any event made in a special ladle.

Between temperatures of 1,350° C. and 1,550° C. the superheating rate is about 5 tons/hr./100° C., with an approximate power consumption of 60 kWh./ton, and the melting rate is approximately 8 cwt./hr. with a power consumption of 670 kWh./ton. At first sight the latter may appear to be on the high side, but it must be remembered this unit has a large furnace body, primarily designed for superheating and holding hot metal, and not for melting. Consequently, the electrical input, at 300 kW., is small in relation to furnace size. This reduces the melting rate, and therefore increases the energy consumption per ton melted.

Although primarily intended as a holding and super-heating unit fed from cupolas, it has a useful melting rate with cold additions, and enables a number of metallurgical operations on special irons to be carried out which could not be performed in either a cupola or a core type of induction furnace. It will also be used in the production of chrome iron and stainless steel castings which, although not widely used, have their place in certain specialist equipment produced by I.C.L.

Furnace and Auxiliary Plant

The installation consists of the furnace itself, mounted in a surrounding charging and operating platform that also carries the pouring controls, and a substation, situated immediately behind the platform, containing the various items of electrical equipment for supplying the furnace with power. At the rear, and elevated relative to the furnace, is the foundry laboratory, from which the furnace can be viewed in action at all times.

The induction coil is wound of a specially shaped section in high conductivity copper. It is designed for maximum electrical efficiency, safety in the event of a metal break through, and free passage for the necessary cooling water. The coil is supported and restrained axially by spring-loaded end rings, and radially by packets of transformer iron, which also constrain the



The fettling pallet conveyor which moves around the grinders and the dual table Wheelabrator. All material is kept off the fettling shop floor

magnetic flux and permit the use of a solidly welded steel outer casing.

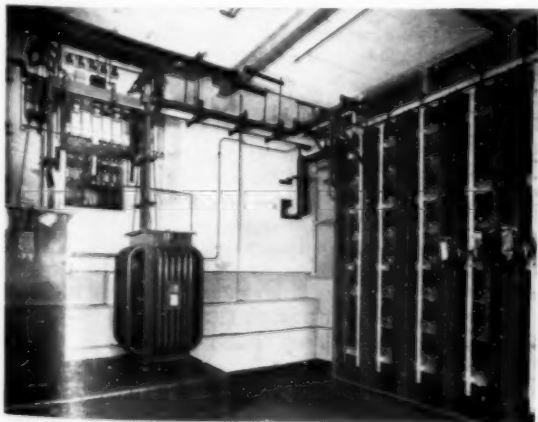
The furnace itself imposes virtually no maximum temperature limitation; only the limit imposed by the chosen lining material need be considered. The first lining of the present furnace is of a high silica material rammed round a sheet steel former that is melted out with the first charge, thereby sintering the lining.

The life of the lining of a mains frequency coreless furnace has been found in practice to be satisfactory up to very high temperatures. When melting iron, it is normally about 150 heats where a pouring temperature nearing 1,500° C. is used. For steel, any number between 30 and 150 heats may be obtained from one lining, depending on the temperature, type of material used, and the care with which repairs are carried out. For light alloys the lining life is indefinitely long—on the Continent, where these furnaces are very popular, not one furnace employed on light metals has been taken out of operation owing to a breakdown of the lining.

The furnace is tilted for pouring by hydraulic rams, one on each side of the body. These are supplied with fluid by a vane type pump controlled by a valve mounted on the control stand on the furnace platform. The rams are of a large diameter resulting in mechanical rigidity and low operating pressures, and thus giving a very smooth and progressive tilting action. The normal pump is driven by an electric motor, but an auxiliary petrol motor driving a stand-by pump is provided for use in the event of a power failure.

The present installation runs off a low tension supply of about 420 volts, which is fed to the equipment through a contactor and an isolator that is mechanically interlocked with the substation access door and with the entrance to the furnace excavation. Access to the substation is only possible when power is off, due to this safety device.

The main on-load contactor is provided with over-load protection, backed up by H.R.C. fuses and an off-load isolator. It is a three phase unit mounted on the supply side of the static balancer. The transformer is provided



Furnace substation showing reactor and transformer on left and above them the water control cubicle and the back of the furnace panel. On the right are the furnace and reactor capacitor banks

with adequate tappings to ensure a wide range of power inputs, so that any degree of superheating or melting, up to the maximum, can be achieved. In the same tank as the transformer is a reactor associated with a static balancer, to give a reasonably balanced three phase load on the incoming supply mains.

In order to present a good power factor to the mains, a bank of 50 cycle power factor correction capacitors is provided, connected in parallel across the coil. This is housed in the sub-station immediately behind the furnace platform and corrects the coil power factor to unity.

Current is brought to the furnace from the busbars by water cooled flexible cables, and coil cooling water is brought by flexible hoses. The water supply is controlled from a cabinet below the instrument panel, and monitoring relays are provided which shut off power and give warning in the event of inadequate flow. As the furnace coil would suffer damage if the water supply were interrupted for more than a few minutes while the furnace was hot, emergency water is provided as a protection.

Five Year Plan for Steel

Sir Andrew McCance Outlines Building Programme

SPEAKING at the Annual General Meeting of the British Iron and Steel Federation in London on March 19th, Sir Andrew McCance, President of the Federation, stated that the industry expects that by next year there should be capacity for the production of 24 million ingot tons of steel—twice as much as was being made at the end of the war—and that thereafter demand for steel may continue to rise by at least a million tons a year. Sir Andrew McCance gave the following outline of the programme to meet this demand up to 1962, covering all stages in the iron-making, steel-making and finishing processes:—

"From the beginning of 1957 the programme includes fourteen new blast furnaces, supported by additional coke ovens, ore preparation plants and sintering facilities; and there will be an improvement in the productivity of existing furnaces. As a result, we expect to have capacity for some 20 million tons of pig iron and ferro-alloys in 1962—7 million tons more than in 1956.

"For steel, eight new or extended melting shops are planned, together with important improvements at several existing melting shops. In turn, the capacity for finished products will be substantially increased, both by the building of new mills and by greater throughput of steel at existing plants. Commentators on these matters naturally tend to concentrate on current shortages. The industry is striving both to overcome these shortages and to work out a balanced long-term programme for all products. For plates, the demand from traditional customers, the shipbuilders, has to be considered with the demand for other important uses such as oil, railway rolling stock and the nuclear energy programme. To supply these needs, six modern 4-high plate mills should come into production between now and 1962, raising the annual output of plates by more than a million tons above the present figure. In the case of heavy sections, a most important addition to output will come from the new universal beam mill to be completed later this year. The output of other products will also be progressively expanded. In short, the plans for development up to 1962 are well advanced. When they are all complete, we are confident that there will be enough capacity to make all the finished steel likely to be required in 1962. Needless to say, formidable problems—for example, raw materials supplies, transport and so on—will have to be overcome to fulfil a programme of such magnitude. These problems are being urgently examined.

"The industry will have to spend, on average, about

£100 million a year on the development programme. Steel prices must therefore be adequate to sustain continuing expenditure on such a scale. The responsibility for determining maximum prices rests with the Iron and Steel Board and not with the industry, and the Board are aware of the position. The steel will be made, but its price must be economic and must take account of the high cost of the new equipment required. The Government can also help, through its taxation policy, and in particular by restoring the investment allowances. Representations to this effect have been made to the Chancellor of the Exchequer."

British Gear Cutting Plant for France

IN 1938 the David Brown Machine Tool Division, Manchester, received enquiries from a French turbine manufacturing company Cie Electro Mecanique, of Le Bourget, for additional gear cutting plant. These negotiations, started twenty years ago, have now culminated in the Manchester firm receiving the largest order for turbine gear cutting machines to be placed by a French company since the war. The outbreak of war prevented the original contract being confirmed, but when the Le Bourget company came to review their turbine machinery requirements in 1947 negotiations were resumed with the Manchester firm, who by this time found themselves competing with German and American manufacturers for the order.

Machines capable of producing gears of great accuracy were stipulated and in order to prove the quality of their products, the Manchester company arranged for French technicians to travel aboard a trans-Atlantic liner driven by turbine gears cut on a David Brown machine. By arrangement with the Cunard Steamship Company two gearing specialists from Cie Electro Mecanique boarded the R.M.S. *Ivernia* at Le Havre and travelled to Tilbury. During the trip they were able to observe the running, under load, of the *Ivernia's* main propulsion gears. On arrival at Tilbury, the gear case covers were removed to allow the French technicians to examine the gearing more closely.

As a result, the Manchester company has been commissioned to supply two machines. One is an M.H. turbine gear hobbing machine, weighing over 100 tons, and capable of cutting gears up to 216 in. diameter. The second part of the order is for a P60 turbine pinion hobbing machine, designed for cutting pinions up to 60 in. diameter and 16 ft. in length.

NEWS AND ANNOUNCEMENTS

Air and Water Pollution Conferences

THE Iron and Steel Engineers Group is arranging to hold two important meetings in the autumn of 1957 on "Air and Water Pollution in the Iron and Steel Industry": the meetings will be held at Church House, Westminster, London, S.W.1, under the chairmanship of Mr. W. M. LARKE. A number of important papers from iron and steel works, plant manufacturers, research associations and other organisations in the United Kingdom and abroad are being prepared for presentation and discussion at the meetings. Preprints of the papers will be available for sale beforehand to all those attending the meetings: the papers and a report of the discussion will be published later in the Special Report Series of the Institute.

It is hoped that wide interest will be aroused by these meetings and that as many as possible of those who are interested will attend and take part in the discussions, whether or not they are members of the Institute or the Iron and Steel Engineers Group.

A two-day meeting on "Air Pollution in the Iron and Steel Industry" will be held on Wednesday and Thursday September 25th and 26th, 1957. The fifteen papers to be presented for discussion deal with the following aspects: treatment of flue gases; coke oven plants; sinter plants; steel plants; general external air pollution; and costs.

The two-day meeting on "Water Pollution in the Iron and Steel Industry" will be held on Wednesday and Thursday, December 11th and 12th, 1957, when seven papers will be presented for discussion, dealing with the following aspects: general technical considerations; coke oven plants; blast furnace plants; pickling plants and integrated iron and steel works.

Further particulars can be obtained from the Secretary of the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1.

B.I.S.R.A. Open Days at Swansea

Since the earlier announcement of the forthcoming Open Days at B.I.S.R.A.'s Swansea laboratories this summer, it has been found necessary to adjust the original dates slightly. The event will, in fact, be held on Wednesday, 19th, and Friday June 21st.

One of the most important of the displays and demonstrations to be mounted will be the P.V.C.-steel laminate project. Developments have reached an advanced stage, and the recently installed pilot line is already producing limited quantities of continuously laminated strip for subsequent user trials. The laminate combines the decorative and durable finish of plastic with the strength of steel, and being capable of severe deformation—it can be bent, crimped, sheared, or even deep drawn—it has a wide range of manufacturing applications. The material can be produced in a variety of colours, and with either a plain or an embossed surface. A similar laminate has been produced in the U.S.A., where the product is finding a ready market. American efforts, however, have been mainly directed towards the production of separate laminated sheets, while B.I.S.R.A.'s

work has been directed to the development of the continuous strip process and general improvement in the laminating process, using materials available in this country.

Formal invitations to the Open Days will be issued to B.I.S.R.A. member firms in the early summer. A general invitation is, however, extended to all industrialists and others interested in coated steel and its many applications, and the Information Officer of B.I.S.R.A. at 11 Park Lane, London, W.1, will be glad to hear from those wishing to attend.

Beilby Memorial Award, 1956

THE Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry and the Society of Chemical Industry, have made an award from the Fund for 1956, of one hundred and fifty guineas, to:—

R. W. KEAR, F.R.I.C., M.Inst.F., in recognition of his work on the behaviour of fuel impurities in combustion processes, with special reference to the role of sulphur, chlorine and alkalies in corrosion and deposit formation by flue gases in combustion appliances.

Awards from the Fund are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering and metallurgy, in which Sir George Beilby's special interests lay. In general, the awards are not applicable to more senior investigators, but are granted as an encouragement to relatively young men who have done independent work of exceptional merit over a period of years. The Administrators are free, however, to interpret this general provision very widely in specific instances.

Institution of Mining and Metallurgy

THE Annual General Meeting of the Institution will be held on Thursday, May 16th, 1957, in the rooms of the Geological Society of London, Burlington House, Piccadilly, W.1. The first part of the meeting, commencing at 4 p.m., will be open only to corporate and non-corporate members of the Institution, but visitors will be welcome to the second part, commencing at 5.15 p.m., when the Institution's awards will be presented and Mr. G. K. Allen will be inducted as President.

Electrons in the Examination of Metals

A Summer School in "The Use of Electrons in the Examination of Metals" will be held in the Departments of Metallurgy and Physics, Cambridge University, from July 9-20th, 1957. Within the last few years important advances have been made in the design of high resolution electron microscopes and in the specimen techniques used for examining metals. Simultaneous with these developments new electron optical methods such as scanning electron microscopy, selected area diffraction, X-ray microscopy and X-ray micro-analysis have been used for examining metals. At the Summer School the

theory and practice of these new techniques will be described. Apart from the main lectures, for which some knowledge of electron microscopy will be assumed, there will be a series of elementary lectures and practical demonstrations for those coming new to this field of research.

The fee for the course is £25: accommodation will be in Pembroke College, Cambridge. Further information and application form for attendance may be obtained from the Secretary, The Board of Extra-Mural Studies, Stuart House, Mill Lane, Cambridge, to whom the completed application form should be returned not later than May 15th, 1957.

I.E.A. Exhibition Conference

THE I.E.A. Exhibition at Olympia in May will be more than a static display of equipment for Instruments, Electronics and Automation. It will be a forum at which techniques and applications will be discussed by internationally-known experts in each field. Each day lectures and discussions will be held at Olympia and admission tickets will be obtainable from the Information Bureau at the entrance to the Exhibition.

A significant aspect of instrumentation and electronics will be dealt with each day. The morning session will consist of a single paper, broadly surveying the field, and in the afternoon, more detailed considerations will be examined. The final programme is still to be completed, but a preliminary list of subjects includes the following:—

Morning Sessions

"The New Age": Nuclear Power; Instrumentation in Industry; The Electronic Office; Instrumentation in Medicine; Instruments as a Career; Communications and the Future.

Afternoon Sessions

Computer Controlled Machines; Automatic Gauging; Reactor Instrumentation; Nucleonics and Isotopes in Industry; Electronic Production Control; Electronics in Banking; The Artificial Heart; Isotopes in Medicine; Training the Electronic Technologist; Training for Research; Ships' Radar; Airport Control.

Among the speakers at the main morning session will be: Rt. Hon. LORD HALSBURY, SIR CLAUDE GIBB, C.B.E., F.R.S., SIR WALTER PUCKEY, SIR GORDON RADLEY, C.B.E., PROFESSOR ROTBLAT and SIR EWART SMITH.

International Congress of Surface Activity

THE first International Congress on Detergency was held in Paris in 1954. It was agreed then that the next congress should be held in England and, under the broader title of the Second International Congress of Surface Activity, this has been arranged to take place in London from April 8th to 12th, 1957. The President of Honour is LORD BRABAZON OF TARA and SIR ERIC RIDEAL, F.R.S. is President. The Organising Committee of which DR. L. H. LAMPITT is Chairman, includes wide representation covering both industrial and academic interests.

A very comprehensive programme of lectures has been arranged by a committee under DR. J. H. SCHULMAN, Head of the Department of Colloid Science at Cambridge University. Authors of these papers come from 18 countries and the subjects cover the full field of surface activity. A programme of works visits has been

arranged by a committee under Mr. M. K. SCHWITZER, and a reception and a banquet have been organised. The papers will all be printed and circulated to members of the Congress in advance. Discussion of the papers will take place in groups after a brief introduction by the authors.

The membership fee for the Congress is £4 and application forms or further details may be obtained from any members of the Committee or from the Hon. Secretary, IInd International Congress of Surface Activity, 14 Belgrave Square, London, S.W.1.

Metal Finishing Conference

THE Annual Conference of the Institute of Metal Finishing will be held at the Grand Hotel, Brighton, from April 9th to 13th, 1957. The programme for this year's conference includes a wide and comprehensive range of technical papers, together with visits to works of interest in the Brighton locality. The programme also provides numerous opportunities for those social contacts and informal discussions which, apart from the organised evening functions, are an important and attractive aspect of such a conference. The following is a list of papers that will be presented at the various technical sessions:—

Wednesday, April 10th.

Morning

- (i) S. A. WATSON and J. EDWARDS: *An Investigation into the Mechanism of Levelling in Electrodeposition.*
- (ii) A. HICKLING and H. P. ROTHBAUM: *The Influence of Periodic Reversal of Current upon the Surface Roughness of Electrodeposited Copper.*

Afternoon

- (i) A. W. BRACE: *Colour Anodising.*
- (ii) G. H. JENNER: *Metal Coatings Produced from Powder by Pressing.*
- (iii) A. H. HARPER, A. MOHAN and S. C. BRITTON: *Electrodeposition of Tin as a Bright Coating.*

Thursday, April 11th.

Morning

- (i) R. PIONTELLI and G. SERRAVALLE: *A Contribution to Knowledge of Cathode Polarisation Phenomena of Nickel.*
- (ii) C. WILLIAMS and R. A. F. HAMMOND: *Change in Fatigue Limit on Chromium or Nickel Plating with Particular Reference to the Strength of the Steel Base.*
- (iii) T. P. HOAR and D. J. ARROWSMITH: *A New Instrument for the Continuous Measurement of Stress in Electrodeposits.*

Afternoon

- (i) W. D. MAY, N. P. D. SMITH and C. I. SNOW: *Adhesion of Surface Coatings.*
- (ii) A. L. NEWCOMB: *Advances in Booth and Oven Design.*

Friday, April 12th.

Morning

- (i) J. MUIRHEAD: *Application of Finishing Materials at Controlled Temperatures.*
- (ii) T. COWLARD: *Airless Spraying.*
- (iii) J. WEBB: *Automatic Spraying.*
- (iv) E. E. V. SHARPE: *Aerosol Spraying.*

Afternoon

- (i) H. SILMAN: *Recent Development in the Cleaning of Intricate Mechanisms.*
- (ii) J. W. CUTHBERTSON and J. E. PARTON: *Automatic Control in Relation to Metal Finishing.*

B.I.C.C. Southampton Office

THE address of the Southampton Branch Office of British Insulated Callender's Cables, Ltd., is now 16/17 Vincent's Walk, Southampton. The telephone number, Southampton 26176/7, remains unchanged.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Bright-Anodised Aluminium Trim

"BRIGHT-ANODISED" aluminium is a development that now seems on the point of acquiring considerable commercial importance in the United Kingdom, largely as a result of recent improvements in brightening and anodising processes. Already in use for motor-car trim—extensively on the Continent and in a small way here—the new finishes are very similar in appearance to chromium plating, but have somewhat higher reflectivity—83% total reflectivity as against 63% total from chromium plating. The cost of the basis metal is lower than that of brass and, although it is higher than that of steel, the finished article in bright-anodised aluminium is generally competitive in price with its chromium-plated counterpart in either metal. A particular advantage is that damage to the film (which is very hard) does not result in discoloration, since the underlying metal is exceptionally resistant to corrosive attack. Moreover, if desired, it is possible to tint the film in a range of light-fast colours, including a brilliant gold.

For bright-anodising, the aluminium must be of high purity; 99.99% pure metal, known as "super-purity aluminium," is used for a wide variety of purposes ranging from reflectors for searchlights to costume jewellery and tableware. For articles in which greater hardness and strength are necessary, super-purity aluminium may be alloyed with magnesium without any deleterious effect on brightening. Northern Aluminium Co., Ltd., have recently developed an alloy called Noral D57S, which contains 1½% magnesium and combines the brightening characteristics of super-purity aluminium with higher strength. Both super-purity aluminium and Noral D57S are available in the form of sheet, strip, and extruded sections, and it is expected that the use of bright-anodised products will spread rapidly as their advantages become known.

A number of brightening processes are available, and several manufacturers in this country have already installed plant for carrying out the brightening and anodising operations. The brightening may be electro-

chemical (the Brytal and Alzak methods are probably the best-known) or chemical (the Erftwerk process here being the most fully-developed). Although the electrochemical processes give the more mirror-like finishes, the Erftwerk process, which is essentially a chemical dip, has a greater smoothing action, and therefore holds out more promise of a reduction in the cost of the mechanical pre-polishing necessary for most applications.

Northern Aluminium Co., Ltd., Banbury, Oxfordshire.

Hypo Clearing Agent

KODAK, LTD., have recently introduced a new chemical which greatly facilitates the removal of hypo from photographic papers, films and plates, and reduces the washing period to about a quarter of that normally necessary, with a consequent substantial saving in water and time. It is, therefore, especially useful for photography on location, for "on site" radiography, and whenever washing facilities are limited. Photographers working in those districts where the water is likely to cause peat staining on prints will find that this trouble can be greatly reduced by the use of this agent.

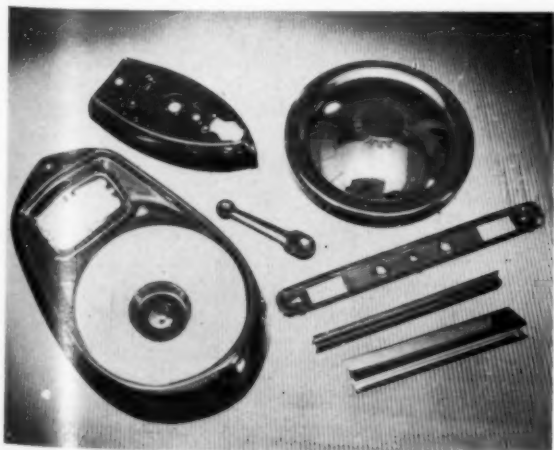
Kodak Hypo Clearing Agent acts as an efficient hypo neutralizer. Films and plates which have been fixed, briefly rinsed and treated for a moment or two in a bath of the clearing agent, need then only be washed for about five minutes, while papers which have been similarly treated require only eight minutes' washing. As the clearing agent will not soften the emulsion layer, no troubles will be encountered with normal heat drying and glazing methods. It is similarly effective when ammonium thiosulphate fixing baths are used.

Kodak, Ltd., Harrow, Middlesex.

High Speed Steel Furnace

A NEW electric double-chamber high speed steel heat treating furnace has been designed by Royce Electric Furnaces, Ltd., for the precision heat treatment of high speed steel tools and similar applications. The furnace has two chambers, one operating at temperatures up to 1,000° C., for preheating and tempering, and one at temperatures up to 1,350° C. for hardening. The two chambers are each 4½ in. wide × 4 in. high × 11 in. long, and are arranged side by side in one furnace body to give the ease of transfer from one chamber to the other which is essential in this class of work.

Protective atmosphere for the high temperature chamber is provided by a Carborundum muffle, which, when heated, produces a neutral atmosphere which prevents scaling. This muffle is interchangeable, and has a working life of 50-100 hr. No gas plant or drip feed device is necessary, and the clean safe working conditions of this protective atmosphere technique will be readily appreciated. The high temperature chamber has long-life silicon carbide resistance heating elements, which are easily removed without any dismantling of the furnace chamber. The control gear incorporates a voltage regu-





lator for the high temperature chamber, and an energy regulator for the low temperature chamber. A temperature indicating instrument is provided for each chamber; alternatively, if preferred, fully automatic temperature control gear can be fitted.

Of special interest are the doors, which, by a hinged arrangement, open so that the steel outer face forms a charging plate and the hot face is turned downwards from the operator. The door has an insulating plug which fits into the entrance vestibule, thus reducing heat losses to a minimum.

The equipment is supplied as a packaged unit comprising twin chamber furnace, control cubicle, floor mounting stand with open work shelves, and closed tool cupboard. All items are separately constructed and suitable for fitting together. The purchaser, may, therefore, buy the furnace for mounting upon an existing bench, and the control box for fitting to a wall, or the whole as a complete self-contained floor mounting unit.

Royce Electric Furnaces, Ltd., Sir Richard's Bridge, Walton-on-Thames, Surrey.

Hydrogen Content Meter

ONE of the main problems connected with the production of aluminium castings is the presence of hydrogen in the molten metal, which results in porosity in the finished casting. With some types of casting, control of this porosity normally entails degassing operations on the melt as called for by the hydrogen content. Rapid



determination of the hydrogen content is thus essential, and for aluminium and its alloys, Edwards High Vacuum, Ltd., have developed, in conjunction with the Laboratories of the British Aluminium Co., Ltd., a robust and practical, but sensitive, instrument for foundry floor use. This instrument, the Telegas, depends upon the diffusion of hydrogen from the melt into nitrogen bubbles; the instrument circulates a stream of bubbles through the molten metal and then into an electrical gas content determination apparatus. The hydrogen will diffuse into the nitrogen until an equilibrium pressure is reached, this pressure being proportional to the gas content of the melt. The nitrogen is circulated through a pumping system of very small volume, to reduce the pumping time to a minimum, and as far as the operator is concerned, it is only necessary to dip a probe into the melt and turn a handle.

The hydrogen content of the gas is measured continuously by a hot wire katharometer with a response time of about 15 seconds. The measuring platinum wire coil is in the gas circuit of the Telegas, and the other coil is open to the atmosphere. The two platinum elements are arranged in a simple bridge circuit and are heated by means of a low current from a 2-volt accumulator. Hydrogen from the metal, picked up by the neutral gas circulating in the Telegas, cools the filament and gives an out-of-balance reading on a suitable millivoltmeter across the bridge.

The Telegas has two ranges of sensitivity and also gives an indication of the temperature of the melt. From the hydrogen equilibrium pressure reading and the temperature, the gas content of the melt may be determined from tables provided.

Edwards High Vacuum, Ltd., Manor Royal, Crawley, Sussex.

Gun Welding Equipment

CHIEF improvement in the new range of portable gun welding equipment introduced by Philips Electrical, Ltd., is the use of a wall-mounted ignitron contactor/timer unit. This means not only that the weight of the transformer assembly is reduced and operator fatigue lessened, but also that all controls are conveniently grouped, with easy access for servicing.

The contactor/timer unit, measuring only $30 \times 30 \times 10$ in. deep, houses two thermostatically-controlled ignitrons and a four-function timer which can be pre-set to control squeeze delay, weld-, hold-, and off-, times. Standard units have a single timer, but two can be fitted to provide independent control for dual gun operation from the same transformer. Transformer assemblies comprise a water-cooled, double-turn secondary type transformer of either 30, 40 or 60 kVA. rating, together with all the necessary ancillary components such as lubricator, air valve, regulators, etc. An important feature is that these components are interchangeable between the three sizes of assembly and also with the Philips range of spot welders. The assemblies are fully tropicalised.

Welding capacities in mild steel are quoted as: 30 kVA.— 2×16 s.w.g.; 40 kVA.— 2×12 s.w.g.; and 60 kVA.— 2×10 s.w.g.. The equipment has been designed primarily for use with Philips own guns, which are available with a wide range of yokes up to 30 in. throat depths, with 1 in., 2 in. and 3 in. stroke, and with either

single- or double-acting cylinders. Any standard spring or air-return type gun can, however, be used. All necessary leads, hoses and connections are provided, and Philips Electrical, Ltd., will also supply a four-wheel, half-ton trolley and a spring balance for suspending transformer assembly and gun, respectively.

Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Argonarc Composite Rectifier

BRITISH OXYGEN GASES, LTD., announce the introduction of a new composite rectifier for their Argonarc welding process. The new rectifier is known as the ACR.150, and has been introduced to meet an increasing demand for small, comparatively lightweight equipment, giving a stable arc down to only a few amperes welding current. Designed initially for the stringent quality requirements of the aircraft industry, this set can be used for welding light gauge materials, with the exception of aluminium and magnesium base alloys, up to approximately $\frac{1}{8}$ in. thick. It has a current range of approximately 10-150 A., but lower currents can be obtained with an external resistance.

Apart from the stepless remote control current regulator, this set can be fitted with a spark starter and a crater-filling device (optional extra), comprising a series of relays, set to operate when the arc is broken at the end of the weld, and causing the current to decay in steps. This device ensures that the weld crater at the finish of the weld cools sufficiently slowly to solidify with the least tendency to cracking. The current steps can be varied to give either a rapid or a slow decay, between 2 and $3\frac{1}{2}$ seconds, according to the thickness of the material and the initial welding current employed.

A striking voltage of 70 is provided, to ensure rapid arc-striking throughout the current range, but more especially at very low welding currents. Argon gas and water time-delay economisers are also provided, which operate automatically when the arc is broken. Remote control of the spark starter and inbuilt contactor is made from a standard 25 V. two-position foot switch.

British Oxygen Gases, Ltd., Bridgewater House, Cleveland Row, St. James's, London, S.W.1.

Controlled Stretched Light Alloy Plates

CONTROLLED stretched Duralumin plates, which were previously available only from the United States, are now being manufactured in this country by a special process developed by James Booth & Co., Ltd. The company has recently supplied to a British aircraft constructor a number of these plates—some of which are believed to be the largest of their kind ever used in this country. The largest plates were 25 ft. 4 in. long, 2 ft. 8 in. wide and 2 in. thick, weighing 1,880 lb. each, and, in spite of their size, had all been subjected to a controlled stretching operation to eliminate the internal stresses occasioned by heat treatment. This method of operation enables plates to be machined without subsequent distortion.

The plates were manufactured by a special process, combining both forging and rolling operations, to ensure that in spite of their thickness they are uniform in mechanical properties and are not subject to the undesirable core effect to which plates of this size are liable



when produced solely by rolling. To ensure that the finished plates were free from internal defects, they were examined by ultrasonic methods at two stages—first as a cast ingot and later as a finished plate.

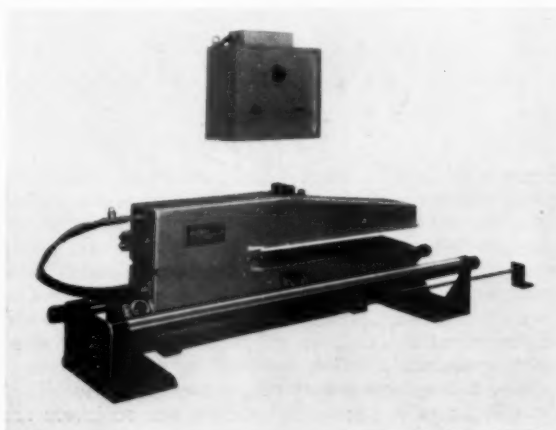
All plates treated in this manner conform to D.T.D. 5010, 5020 or 5050, and are claimed to be particularly useful in methods of construction where components have to be machined from thick plates. Although the size of the plate quoted is believed to be the largest yet made in this country, it is claimed that plates up to 35 ft. long can be supplied if required, subject to a maximum cross-sectional area of 65 sq. in.

James Booth & Co., Ltd., Argyle Street Works, Birmingham, 7.

Head Bracket for Nucleonic Thickness Gauges

NUCLEONIC thickness gauging is now a fairly well established practice in many industries. Baldwin Instrument Co., Ltd., has now developed a cast aluminium alloy "C" bracket which is mounted on four ball races to facilitate easy traversing. There are three sizes of throat depth available—12, 27 and 42 in.; and four standard gap sizes— $\frac{1}{8}$, 1, $1\frac{1}{2}$ and 2 in.

The bracket is made movable so that: (a) the head can be withdrawn from the web for standardising; (b) the position of the head can be adjusted for varying widths of material; (c) the head can be moved to



different positions relative to the material; and (d) the head can be continuously traversed, giving information on weight or thickness variations across the entire width of the material. At present there are two methods of operation, manual and pneumatic.

For installation where there is no gangway by the side of the machine sufficiently wide to accommodate the bracket when fully withdrawn, a special mounting arrangement is being developed. This will consist of two end pieces placed either side of the machine and joined together by two tie bars, located one below the web and the other above. The source will move along the upper tie bar and the chamber along the lower.

The radioactive source when used in a "C" bracket is fitted with a shutter which can be operated manually, electrically, or pneumatically. Lamps can be fitted to indicate whether the shutter is open or closed.

Baldwin Instrument Co., Ltd., Brooklands Works, Dartford, Kent.

Oil Meter For Low Flows

THE new CM Low-Flow Oil Meter announced by George Kent Ltd., is of the semi-positive, rotary-piston type, for flows up to 200 gal./hr., and is for installation in pipelines of between $\frac{3}{4}$ in. and $\frac{1}{2}$ in. (9.5 and 12.7 mm.) bore. It conforms to stringent specifications and was developed to meet an urgent demand, from both home and overseas, for accurate and dependable measurement of low oil flows. An important application is the recording of the fuel consumption of small oil-fired furnaces



increasingly used in industry and commerce. The many special features of the CM include: accuracy within 2% from 1.5 gal./hr. to 200 gal./hr; compact design and simplicity of construction; all meter parts easily replaceable in the event of excessive wear or accidental damage; straight-reading counter with first-class dial clarity; high working pressures and low head loss; and all components manufactured from selected corrosion-resisting materials.

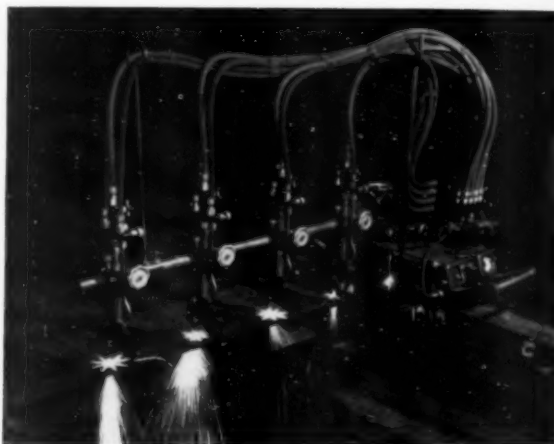
The semi-positive, rotary-piston operating principle of the CM meter is one with which water engineers are

already familiar, although it is equally applicable to the measurement of all liquids. In this type of meter the flow, entering through a shaped inlet part, continuously drives a piston in an eccentric path around an accurately machined measuring chamber, each revolution representing a given volume of liquid passed through the meter. The rotary movement of the piston is employed to open and close alternately the inlet and outlet ports of the measuring chamber, as well as to drive the counter mechanism of the meter. The most outstanding advantage that this type of meter has over all others, is its ability to register accurately very low flow-rates, while still retaining excellent high-flow performance.

George Kent, Ltd., Luton, Beds.

Strip Cutting Machine

A PROBLEM in many engineering works is the difficulty of obtaining ready-cut steel strips: steel companies are now providing steel plates for the customers to cut themselves. The equipment normally used for this purpose enables only one strip to be cut at a time, but the process can now be speeded up, as a result of a new Strip Cutting



Machine which has been produced by the North Eastern District of British Oxygen Gases, Ltd.

The new machine is based on the Heavy Weight Tractor. A bar is mounted on the tractor and on the bar are fixed four Portable Straight Line cutting blowpipes. The maximum width between the extreme cutters is 3 ft. and the minimum width between cutters $2\frac{3}{4}$ in. The machine runs on a 10 in. track and produces parallel strips efficiently and speedily: it requires little space and is easily transportable. One of these machines was recently installed at the Constructional Works of the South Durham Steel and Iron Co., Ltd., at Stockton, and as an example of its performance may be quoted the cutting of a 45 ft. 8 in. long $\frac{3}{4}$ in. plate with four cutters set at $7\frac{1}{2}$ in. pitch in an hour.

British Oxygen Gases, Ltd., also market a large Strip Cutting Machine, based on the Oxyplane design, and on which can be mounted up to twelve cutters. One of these machines is soon to be installed at the Bridge and Constructional Works of Dorman Long (Bridge & Engineering), Ltd., at Middlesbrough.

British Oxygen Gases, Ltd., Bridgewater House, Cleveland Row, St. James's, London, S.W.1.

CURRENT LITERATURE

Book Notices

BRITISH SCIENTIFIC AND TECHNICAL BOOKS (1935-52)

A select list of recommended books published in Great Britain and the Commonwealth in the years 1935 to 1952. Published for Aslib by James Clarke & Co., Ltd., London, and Hafner Publishing Company, U.S.A. 63s. net (postage 1s. 9d.)

THE WANT of a comprehensive bibliography of British scientific and technical books published during the last quarter of the century has been felt severely by librarians and, perhaps still more, by students of science and technology. This period is one of exceptional significance in these fields, and British authors and publishers have not been slow to add their contribution to the great body of published knowledge. Nevertheless, until the British National Bibliography began to appear in 1950, the only extensive bibliography of British books in this particular field of science and technology was the admirable *Catalogue of British Scientific and Technical Books*, the third and last edition of which was published by the British Science Guild in 1930.

This new publication, one of Aslib's major compilations since the Second World War, represents an attempt to fill the gap, or at any rate a major part of it. The entries in this bibliography represent the most important and useful books on science and technology published in the United Kingdom and the Dominions between 1935 and 1952. The latter date has been chosen to ensure sufficient overlap with the early issues of the British National Bibliography.

Books in all the divisions of pure and applied science are represented, together with those publications in such fields as psychology, documentation, architecture and photography which are of interest to technical readers. The economic and social sciences, which were poorly represented in early issues of the *Aslib Book List* have been excluded, and certain semi-technical subjects such as gardening and domestic science are covered less thoroughly than, for example, electrical engineering. The intention has been to ensure representation of as many subjects as possible, even at the risk of including, in certain sections, books of a slightly lower standard than that of the majority. Nevertheless, every effort has been made to include only those books which have made a useful contribution to the understanding of the subject by laymen, students and advanced workers.

The entries in the main body of the work are classified and arranged by the Universal Decimal Classification. Under each class heading the entries are arranged alphabetically by author, and an author index to the classified section is provided. The latest edition of a book has been shown in each case and the place of publication has been given for all books not published in London. In order to simplify entries, the presence of illustrations or bibliographies only is noted, and, wherever it could be ascertained, the date of the previous edition is given in brackets following the series title. In addition to the classification by subject, each book is further classified by the following symbols: (a) books

suitable for general readers, or treating the matter in an elementary manner; (b) books of an intermediate degree of technicality, or suitable as textbooks for students; (c) books of an advanced or specially technical character; and (d) reference books, including dictionaries, encyclopaedias, etc.

HIGH CONDUCTIVITY COPPER ALLOYS

54 pp., 25 tables, numerous illustrations. Published by The Copper Development Association, 55 South Audley Street, London, W.1. Gratis.

THE Copper Development Association has added to its list of technical publications a booklet entitled "High Conductivity Copper Alloys." This booklet of fifty four pages deals with four copper alloys—cadmium copper, chromium copper, silver copper and tellurium copper—which have many applications in the electrical industry and, in general, for purposes where high electrical and thermal conductivities are required. The composition, production, and physical and mechanical properties, etc., of each alloy are discussed. There are twenty five useful tables, as well as equilibrium diagrams, and photographs illustrate typical applications of the four alloys.

B.S.I. YEARBOOK FOR 1957

Published by the British Standards Institution, 2, Park Street, London, W.1. 15s. + 1s. 6d. postage.

As usual, 400 pages of the current 480-page Yearbook of the British Standards Institution are devoted to a complete numerical list of the British Standards and Codes of Practice current on January 1st, 1957; these total approximately 3,000. Apart from its main purpose as a reference directory to all current British Standards, the Yearbook contains a lot of other information about B.S.I. and the services it offers, including notes on the British Standards mark of approval (the Kite) and the standards to which it is applied, and details of the Canadian Approvals service whereby electrical gear can be "approved" for export to Canada before leaving this country. Other information covers lists of addresses in the United Kingdom and overseas where complete reference sets of all British Standards can be consulted, while the Yearbook also contains a comprehensive index in which all standards are listed according to subject.

Trade Publications

THE Refractories Section of the Consett Iron Co., Ltd., have been making silica bricks for over 50 years. Bricks, shapes and cements of siliceous materials are today made at the Templetown Silica Brickworks, but the Company has extended its facilities by the construction of a modern high temperature refractories plant at Jarrow-on-Tyne where basic refractories of the magnesite, chrome-magnesite, magnesite-chrome and chrome type are produced. In a recently-published brochure, particulars are given of the complete range of high grade refractories

manufactured by the Company, which include also high alumina and zirconia bricks and cements.

A NEW brochure on titanium has been received from Titanium Metal and Alloys, Ltd., which is jointly owned by Henry Gardner and Co., Ltd., and Samuel Osborn and Co., Ltd. Particulars are given regarding room and elevated temperature properties, weldability and corrosion resistance. Further sections deal with the applications of titanium and with the Company's fabricating facilities at Sheffield, concluding with the details of the sizes of sheet, rolled bar, forged bar, forged blanks and rings available therefrom.

GRIFFIN AND GEORGE, LTD., have recently completed the distribution of their new Chemical Laboratory Apparatus Catalogue (56S). This is the major publication of the Company which was formed in July, 1954, by the merging of Griffin and Tatlock, Ltd., W. & J. George and Becker, Ltd., and Standley Belcher and Mason, Ltd. It comprises some 700 pages of factual text, well illustrated, dealing with over 20,000 items covering the general chemical apparatus requirements of those engaged in education, industry and research.

WE have received from Alar, Limited, the latest of their individual data sheets, which describes the properties and characteristics of the aluminium-silicon-magnesium alloy to B.S.1490, LMS, in the as-cast and heat-treated conditions.

THE latest Norton Grinding Wheel Co., Ltd., leaflet deals with the new Metalite Series 48 abrasive cloth belts which are made by the associated company, Behr-Manning, Ltd.

WE have received from Hadfields, Ltd., an illustrated brochure describing the range of single-toggle breakers and granulators made by the Company. There are five sizes of breaker whose outputs on grinding hard limestone to 2½ in. ring range from 3 to 15 tons per hour. The granulators, intended for further reduction to sizes suitable for top dressing, have outputs based on hard limestone to about ¾ in. cube, ranging from 3 to 10 tons per hour.

CHARLES CARR, LTD., (incorporating The Non-Ferrous Casting Co. (B'ham), Ltd.) which at the time of its founding almost a century ago specialised in the casting of church bells, has recently issued a brochure containing concise information on the various non-ferrous metals which the Company now produces. These include gun metals, bronzes, leaded bronzes, aluminium bronzes, manganese bronzes and brasses available as chill-cast solid and cored bars, or as castings up to 2 tons in weight. A recent development is the application of the shell moulding process to these materials. Specialised products include railway axle-box bearings and brazing solders. A separate booklet lists the "Lily Brand" non-sparking tools made by the Company.

PHOSPHATE, oxalate and other allied organic and inorganic coatings in the well known "Bonderizing" range have played an important part in overcoming difficulties in working many of the new metals and alloys such as titanium, zirconium, Nimonic and even stainless steel. Significant advances have also been made recently in the application of "Bonderite" coatings to very deep drawing operations, to the cold extrusion of steel and to cold heading. A number of present day stories of these contemporary developments are collected in the pages

of the January, 1957 issue of *The Bonderizer*, published by the Metal Finishing Division of the Pyrene Co., Ltd.

A NEW technical circular (T.C.107) issued by Quasi Arc, Ltd., of Bulston, Staffs, describes the Fusarc/CO₂ Automatic Arc Welding Process which the firm has recently introduced. The process has major applications in the shipbuilding and automobile industries.

IT is now the practice of The Solartron Electronic Group, Ltd., Thames Ditton, Surrey, to produce an illustrated Annual Review of the year's progress in which is included a special survey and explanation of an important electronic topic. This year the subject is "Electronics—The Spearhead of Automation," by Mr. Bowman Scott, M.B.E., a Director of the Group and the Managing Director of Solartron Electronic Business Machines, Ltd. The treatment is simple and with direct explanations (aimed at providing a general understanding of the subject). Some of the examples of the applications of electronics in automation are illustrated by reference to Solartron electronic instruments.

LITERATURE referred to in the October-November issue of *The Nickel Bulletin* includes a comprehensive survey of nickel developments in Canada (with additional notes on world conditions in the nickel industry), new American Welding Society specifications for welding rods and electrodes for joining nickel and nickel alloys, and an amplified edition of the atlas of isothermal transformation diagrams of B.S. En steels. A further item of particular interest in relation to construction steels is a summary of papers presented at a recent symposium on fatigue. The section of the Bulletin concerned with heat- and corrosion-resisting materials contains abstracts reporting further study of the phenomenon of corrosion by vanadium pentoxide, and a review of information on atmospheric corrosion contributed to the 1955 meetings of the American Society for Testing Materials.

Books Received

"Applied Strength of Materials." By A. Jensen. 343 pp. inc. index. New York, Toronto and London, 1957. McGraw-Hill Book Company, Inc. 43s.

Finishing Handbook and Directory, 1957. Edited by I. S. Hallows. 485 pp. London, 1957. Sawell Publications, Ltd. 37s. 6d. (including twelve monthly issues of *Product Finishing*), plus postage.

"Protective Painting of Structural Steel." Prepared by F. Fancutt and J. C. Hudson for the Protective Coatings (Corrosion) Sub-Committee of the Corrosion Committee of the British Iron and Steel Research Association. 102 pp. inc. index. London, 1957. Chapman and Hall, Ltd. 21s. net.

"The Mechanism of Phase Transformations in Metals." A Symposium organized by the Institute of Metals and held at the Royal Institution, London, on 9th November, 1955. Institute of Metals Monograph and Report Series No. 18. 346 pp. London, 1956. The Institute of Metals. 50s. (\$7.50).

"Handbook for Welding Design." Vol. 1. 305 pp. inc. subject and name indexes. London, 1956. Sir Isaac Pitman & Sons, Ltd., for The Institute of Welding. 45s. net.

"Métallurgie." By R. Cazaud. 66th Edition. Vol. II. Aide-Mémoire Dunod. Paris, 1957. Dunod. 480 F.

LABORATORY METHODS

MECHANICAL • CHEMICAL • PHYSICAL • METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

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The Importance of Analytical Research in the Iron and Steel Industry

by D. Valerie Swindell

Sheffield Laboratories, British Iron and Steel Research Association.

Some recently developed analytical techniques are reviewed and an account of their application to specialised problems in metallurgical research is given. The saving in time gained by using instrumental methods in works' practice is also mentioned.

A SIGNIFICANT increase in the output of the various steel consuming industries during the last decade has resulted in correspondingly increased demands on the iron and steel industry. In order to retain the consumer's confidence whilst the increased output is achieved, the steelmaker must ensure the maintenance of his quality standards. One of the most important quality checks made for this purpose is the chemical analysis of the steel, to confirm that it meets the appropriate specification.

As a result of numerous investigations on the properties of iron and steel, it has been established that certain elements are undesirable in various grades of these materials, or that they are only necessary in limited quantities. It has also been shown that failure of manufactured products is sometimes due to the presence of "foreign" metallic or non-metallic inclusions. Apart from routine checking, research workers in the metallurgical field rely on the information gained from physical and chemical analysis as a means of furthering their investigations. One of the purposes of this article is to indicate the valuable role which specialised analytical work can play in support of metallurgical research.

Speed and accuracy are of fundamental importance to the analyst, because he must cope with an increasing number of samples of diverse specifications, many of them calling for very close tolerances on composition limits. Much of the work of developing and standardising methods of analysis for production control and referee analysis is carried out collaboratively within the steel industry, under the auspices of the British Iron and Steel Research Association, and is eventually published as a British Standard.

The following description deals with modern analytical techniques and their application to research and quality control in the iron and steel industry.

Colorimetric Methods

Several alloying constituents in steel will form soluble coloured compounds, and in most cases the depth of these colours may be related to the actual concentration of the element. Colorimetric procedures are now used extensively in ferrous analytical laboratories where speed of routine analysis is essential, because by their applica-

tion an increase in the speed of analysis may be achieved without loss of accuracy.

The adaptation in 1941 of the Spekker photoelectric absorptiometer to ferrous analysis¹ obviated many long and tedious determinations. Briefly, a beam of filtered light from a tungsten or mercury vapour lamp is allowed to fall on an indicating photocell. This is connected in parallel opposition with a compensating photocell across a galvanometer, so that when equal quantities of light fall on each photocell the galvanometer deflection is zero. When a coloured solution is placed in the light path of the indicating photocell, the light energy falling on the photocell is reduced, with a consequent deflection of the galvanometer. To rebalance the galvanometer it is necessary to increase the light incident on the indicating photocell. This is conveniently effected by the rotation of a calibrated drum, operating a variable aperture which moves in the light path. Suitable filters are selected in order that the light falling on the indicating photocell may be of a limited waveband. In conjunction with a mercury vapour lamp, this provides an approximation to monochromatic light.

If it is necessary to measure the optical density of a coloured solution at a pre-selected wavelength, monochromatic light may be used, because the wavelength corresponding to the optimum transmittance of any one coloured solution may then be selected. A simplified spectrophotometer—the Unicam SP600 (Fig. 1)—for accurate colorimetric measurements within the visible and near infra-red regions of the spectrum has been described². The design of the instrument is such that a single beam of nearly monochromatic light passes through the coloured solution on to a selected phototube. The output of the phototube is balanced by a potentiometer which is calibrated in terms of optical density and percentage transmittance. The light source is a tungsten filament lamp, and the optical system, which is of the Littrow type, makes use of a 60° flint glass prism. Wavelength selection is made possible by rotation of the prism table. A curved slit is used as entrance and exit slits in its lower and upper regions, respectively, and the mirrors are silvered on their front surfaces. Although the slit width control is not calibrated, the spectral band width is claimed to be less



Fig. 1.—The use of the Unicam S.P.600 spectrophotometer in micro-chemical methods of analysis.

than $3m\mu$ over most of the wavelength range—350–1,000 $m\mu$.

Colorimetric procedures are usually found to be more sensitive than either gravimetric or volumetric procedures, and consequently it is possible to effect a saving in time and materials by the use of smaller sample weights. These methods find their best application in analyses in the lower concentration ranges. A comparison between the time taken for the analysis of ten samples by conventional and colorimetric methods is given in Table I. The times given have been measured in the author's laboratory.

TABLE I.—TIME TAKEN FOR THE ANALYSIS OF TEN SAMPLES BY CONVENTIONAL AND COLORIMETRIC METHODS.

	Conventional Method		Colorimetric Method	
	R.S. 1121 Part No.	Time In Hours	R.S. 1121 Part No.	Time In Hours
Silicon	10	3½	19	1½
Manganese	16	1	23	1
Nickel	6A	2½	6B	1½
Chromium	13	1½	24	1½
Molybdenum	20	1½	34	1½

* Time taken for a single determination.

The application of colorimetric methods of analysis has resulted in the development of composite schemes of analysis which enable several elements to be determined colorimetrically from a single sample, for example ten samples may be analysed for manganese, nickel, chromium and molybdenum in about three and a half hours.

Spectrographic Methods

Spectrographic techniques have been developed from simple spectroscopic principles, and it has been proved that for both quantitative and qualitative analysis reliable results can be obtained. Basically, the material under test is vaporised by means of an electric discharge, caused to pass between the sample and an upper electrode (Fig. 2). The light emitted as a result of the excitation of the metal vapour is passed through an adjustable slit, and it is possible to relate the composition of the light to the sample content, since the spectrum produced by each element is characterised by a definite system of wavelengths. A rapid quantitative

determination may be performed by exposing a photographic plate to this light emission, and by subsequent comparison of the densities of the spectral lines with those of the same elements present in standard samples.

An accessory for the spectrograph has been devised, whereby the sample may be traversed during analysis and the photographic plate moved at a relative speed by a gearing mechanism.³ It is possible to determine by examination of the resulting spectrogram whether or not the steel is of uniform composition.

Measurement of the intensities of spectral lines may be effected automatically in the direct reading spectrograph. The photographic plate is replaced by photosensitive tubes which measure the intensity of chosen spectral lines and, through an electronic system, give a direct reading of the content of the sample. The speed of analysis is thereby increased even further, since the time taken for development and comparison of photographic plates is saved. Speeding-up of bath sample analysis has been achieved in industry by the employment of such an instrument in the melting shop control laboratory. From the time of dispatching the bath sample to the receiving of the results, six or seven elements in a low alloy steel may be analysed by one operator in only ten minutes. Two analysts would spend approximately one hour determining the content of the same elements by chemical methods. A recent paper⁴ describes production control using a direct reading spectrograph. Instruments are being developed which will analyse carbon, sulphur and phosphorus, and the future applications of these techniques for routine analysis promise to be extensive in works' laboratories.

Some Special Techniques

When suitable colorimetric and spectrographic procedures cannot be used, special methods are adopted which may, for example, incorporate mercury cathode separation, ion exchange, or even vacuum fusion techniques. Collaborative analysis in the steel industry has also been responsible for the development of special analytical techniques for the analysis of standards for both chemical and spectrographic analysis, such as the comprehensive series issued by the Bureau of Analysed Samples, Ltd.

The steelmaker seeks to improve ingot production by counteracting the harmful effects of physical and chemical changes which may take place during the casting and solidification of an ingot. For example, the presence of oxygen in the steel after refining results in the evolution of carbon monoxide, causing the formation of blow holes in the finished ingots. This reaction may be controlled by the addition of deoxidising agents such as aluminium. In the study of deoxidation problems, an accurate knowledge of the oxygen content of the finished ingot is essential and this may be conveniently determined by a vacuum fusion technique. An all-metal vacuum fusion apparatus has been designed for operation in a melting shop control laboratory⁵. Using a four-stage mercury vapour diffusion pump, a high vacuum is obtained under which a graphite crucible is heated by induction to 2,300° C. After the extraction of residual gases from the system, the temperature is lowered to 1,600° C. and the solid samples are drawn magnetically into the crucible. The carbon monoxide, hydrogen and nitrogen evolved are collected and analysed. The gases are compressed to a known volume, at which stage their pressure is recorded, and then oxidised at 600° C. by a

mixture of copper and ferric oxides. The water produced is absorbed in phosphorus pentoxide and the pressure is again recorded. The carbon dioxide may be frozen out in liquid oxygen, leaving only the nitrogen. Alternatively, the nitrogen may be pumped away from the solid carbon dioxide, which is then re-evaporated and its pressure recorded.

In addition to the importance of the oxygen contents in steelmaking, much attention has been paid to the deleterious effects which take place in a steel ingot due to contraction. During the cooling of a killed steel ingot, cavity formation takes place due to contraction. It is therefore desirable to maintain a reservoir of molten steel at the head of the ingot in order to provide a feed of metal into the contraction cavity and ensure a sound ingot. Research has shown that the type of refractory used to contain the feeder head influences the feeding efficiency and, consequently, the ingot yield. An exothermic refractory reduces the heat losses and therefore allows a smaller volume of feeder head, resulting in a reduction in the weight of top end discard. Suitable exothermic materials contain aluminium. Spectrographic analysis lends itself to the determination of aluminium pick-up in feeder heads cast in these materials, and results indicate the extent to which the unreacted aluminium has dissolved into the steel. Analytical results also show that a reduction in the aluminium pick-up by the steel is obtained if the inner face of the exothermic material is subjected to a refractory wash prior to casting.

The quality of silicon-iron sheet used in the construction of soft magnetic cores for the electrical industry must be maintained at the highest level in order to obtain the maximum efficiency from the material used. For example, largely by improvement in the quality of silicon-iron, the transformers constructed to-day are only one-third the size of those built fifty years ago for the same duty, and this has resulted in a considerable saving. A study of the magnetic properties of high purity silicon-iron has indicated that significant decreases in static hysteresis losses are obtained by reducing the nitrogen content⁶. For example, if the nitrogen level is reduced from 0.005 to 0.0025 wt.-% (which is within the range present in commercial material) then the hysteresis loss will be reduced by approximately one half. This corresponds to a reduction in total losses of about 10-15%. A reduction in total losses of about 5% for transformers used in the electricity supply industry is equivalent to a saving of a quarter of a million pounds per annum. The silicon-iron is denitrided and decarburised in flowing hydrogen, and careful analysis is necessary to indicate whether these elements have been removed to the desired low limit.

The measurement of the nitrogen content has for some time presented difficulties to the analyst, since discrepancies arise due to nitrogen from other extraneous sources. A new procedure⁷ for the determination of nitrogen has been developed which is based on the classical principle of distillation as ammonia. Close attention has been paid to the possible insoluble nitrides present in the sample, and recent methods incorporate a centrifuging technique by which they may be removed. By suitable treatment with fuming sulphuric acid, it is possible to decompose the majority of the nitrides. The nitrogen present may then be reported as a total content, or separately as soluble and acid-insoluble nitrogen. Although carbon is not so deleterious as nitrogen in



Fig. 2.—The spectrographic examination of a table knife, using the Hilger large quartz spectrograph.

silicon-iron, it is still desirable to keep it at a low level, and a special procedure has been developed for the determination of carbon at the low levels of about 0.001% obtained under experimental conditions.⁸ The sample is ignited in a stream of oxygen at a temperature of 1,150° C. and the evolved carbon dioxide is passed through precipitated manganese dioxide to remove the sulphur dioxide present, after which the carbon dioxide is led into a freezing trap, maintained at a low temperature with liquid oxygen. Excess oxygen present in the trap is removed by evacuating the system, and the solid carbon dioxide is then evaporated and expanded into an evacuated calibrated bulb, where the actual volume of gas is measured by recording the increase in pressure on a manometer.

Much research into various phenomena affecting the quality of commercial steels requires a supply of high purity iron, and this warrants an investigation into its production. The yield-point of iron, the rates of diffusion of various elements into the material and the production of certain iron alloys, such as the silicon-iron already referred to, are among the many research projects carried out by workers at universities and in steel companies in Britain and abroad. High purity iron is produced by vacuum-refining specially pure commercial iron, followed by re-melting under dry hydrogen⁹. The deoxidised product contains less than 0.03% total impurities, and the determination of such small amounts presents considerable analytical problems. Mercury cathode separation¹⁰ is one of the special techniques employed in the trace analysis of both high purity iron and highly alloyed steel. The electrolysis of a solution of the sample in perchloric or sulphuric acid by a current of 15 amp. presents a means of removing all the iron present. Mercury, which forms a cathodic pool in the water-cooled cell, forms an amalgam with the iron, nickel, chromium and any other heavy metals which may be present. Subsequent analysis of trace elements, such as titanium, vanadium, aluminium and phosphorus is greatly simplified. The carbon content may be determined by the low pressure method already mentioned, and vacuum fusion techniques are employed for the determination of nitrogen and oxygen in high purity iron.

The addition of small amounts of boron to certain alloy steels is beneficial; it has been shown that boron, to the extent of about 0.003 wt.-% can be used to replace some alloying elements in steel—for example, nickel, chromium and manganese—with improved hardenability.^{11, 12} From the point of view of alloy conservation this is very advantageous, although a complete investigation into the other effects of boron on the steel is desirable. The mechanism by which the enhanced hardenability of steel is achieved is not yet fully understood, but it is known that boron does influence the rate of ferrite formation, when the boron is in solid solution. Briefly, the problem is to discover the influence of boron on the nucleation of the new phase during the transformation. From theoretical considerations it is probable that boron migrates preferentially to the grain boundaries where nucleation occurs most readily. Internal friction measurements, based on the movement of solute atoms within the iron lattice, give the diffusion rate of boron, which influences its movement from one lattice site to another during the transformation. Two other important factors governing the effect of boron on hardenability are its solubility and the type of solution which it forms with the iron. These data are also obtained from internal friction measurements. In boron steels, carbon contents should generally be less than 0.3%, otherwise the effect of boron on hardenability becomes less pronounced. The effect of nitrogen is similar to that of carbon; consequently, an exact knowledge of the carbon and nitrogen contents, as well as the boron content is essential. Ion exchange separation techniques have been applied to the procedure for the determination of boron.¹³ After the removal of iron by adsorption on a resin column, the boron is determined colorimetrically as a complex of dianthramide. Carbon contents are determined by the low pressure method, and the distillation procedure is employed for nitrogen analysis. Once again the significance of reliable analytical methods for maintaining a special steel within specification is evident.

The production of highly alloyed steels of superior quality is of major importance in the Sheffield steel industry. One of the important types of tool steel is high-speed steel, which contains tungsten, chromium and vanadium. Owing to poor distribution, carbides form clusters in the steel, which are more pronounced at the centre of an ingot, and which cause trouble in working and weaknesses in the finished tool.¹⁴ Analysis shows that this segregation of carbides is not due to a difference in carbon content within the ingot, but depends on the method of solidification of the steel. In order to determine the composition of the carbide segregates microchemical analysis is employed, and results indicate, for instance, to what extent the sulphur present is associated with the eutectic. Inoculation of the high-speed steel is also under investigation, involving the addition of traces of various elements or compounds which might form nuclei at which solidification of the steel may commence, and so refine the grain structure. The amount of inoculant and, particularly, its form in the melt are very critical, and call for unusual skill and ingenuity on the part of the analyst to establish these conditions.

Impaired properties in many types of steel are due to discontinuities caused by the presence of non-metallic inclusions, which may be introduced from the slag or refractories, or may result from reaction in the steel. Many of them may be identified microscopically, but

sometimes confirmatory evidence is required. Several chemical methods are available for the separation of non-metallic inclusions, including the chlorination¹⁵ and the alcoholic-iodine methods.¹⁶ Carbide phases may also be separated electrolytically from highly alloyed steel¹⁷ and it is sometimes possible to extract the inclusion with a fine needle drill. The residue after separation may be analysed by micro or semi-micro methods. Microchemical analysis is a specialised technique¹⁸ applicable to many types of analytical work, and provides a means for qualitative and quantitative determinations where the quantity of available sample is small. The size of the glassware has been adapted to accommodate the small volumes of solution used. An air-damped balance capable of recording 10⁻⁶g. is necessary, together with a combustion furnace used for the determination of carbon and sulphur¹⁹ in a 50 mg. sample. Microchemical techniques may be applied to the analysis of segregates and inclusions, since the amount of sample available is invariably limited. For most estimations it is possible to adapt existing macrochemical procedures to the small scale required. Spectrographic traversing has also been employed in order to analyse a specific inclusion, but the use of these techniques is limited to low alloy steels and to the identification of only certain elements. After suitable arrangement of the sample, such that the suspected inclusion passes beneath the upper electrode, it is possible to determine from the spectrogram whether or not an inclusion is present and, if so, a direct comparison of its composition with that of the matrix may be made.

The examination of products which have failed during service is another problem which is presented to both the metallurgist and the analyst. When analysis is required in furthering these investigations, methods are used which incorporate many of the special techniques.

A study of the mechanism of corrosion provides a life-long research for many scientists, and chemical investigations into the composition of products obtained as a result of both atmospheric and sea-water attack of test samples, assists in the development of corrosion inhibition. A standard of high quality in manufactured products will not be maintained if corrosion occurs during storage or transit. It is, therefore, essential to select the most suitable packaging materials, so that the product reaches the consumer in perfect condition. The corrosion of stainless steel tableware and penknives has been studied, and attention has been paid to the possible effect of wrapping paper on the steel. The necessity for an investigation into the composition of wrapping materials was considered to be essential, and standard methods have been adapted to deal with samples where analysis is not straightforward.²⁰ Tests show that acidity and a high chloride content are always characteristic of materials which have caused corrosion. From an aqueous extract of the paper, the hydrogen ion concentration measurements may be made by using a glass electrode, and the chloride content is estimated by a potentiometric method or by the classical Mohr or Volhard titrations. Decorative wrapping and display papers and certain varieties of cardboard often produce highly coloured aqueous extracts which interfere with the end-point of

Conclusions

The techniques described have been developed so that analyses may be performed and accurate results obtained in the minimum time. All the apparatus described is available commercially and the methods are in practice in many metallurgical laboratories.

Information gained from analytical results assists developments in the iron and steel industry ranging from the selection of suitable foreign ores to technical information for the user of the finished product. The reliance placed on these results is a satisfying reminder that the analytical chemist is helping in the work to achieve a high quality in iron and steel and an ultimate increase in their production.

Acknowledgments

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preparation of this article, which is published by permission of the British Iron and Steel Research Association.

REFERENCES

- 1 E. J. Vaughan. The Use of the Spekker Photoelectric Absorptiometer in Metallurgical Analysis, Royal Institute of Chemistry Monograph, 1941.
- 2 D. R. Curry and P. H. Scholes. *Metallurgia*, 1956, **54**, 143-149.
- 3 J. K. Hursvita. *Spectrochimica Acta*, 1955, **7**, 1-13.
- 4 B. Manderfield and W. S. Sykes. *J.I.S.I.*, 1957, **155**, 105.
- 5 K. Speight and G. M. Gill. *Metallurgia*, 1957, **55**, 155-158.
- 6 G. M. Leak and D. A. Leak. Private Communication.
- 7 "Standard Methods of Analysis." The United Steel Companies Ltd., Sheffield, 1951, 53-59.
- 8 R. M. Cook and G. E. Speight. *The Analyst*, 1956, **81**, 129-184.
- 9 R. E. Hopkins, G. C. H. Jenkins and H. E. N. Stone. *J.I.S.I.*, 1951, **163**, 377-383.
- 10 B.S. 1121 C: 1955—Mercury Cathode Electrolysis.
- 11 L. J. Rohl. *J.I.S.I.*, 1954, **170**, 173-187.
- 12 G. M. Leak. *Metal Treatment and Drop Forging*, 1956, **23**, 21-28.
- 13 H. G. Short. Unpublished work.
- 14 E. Ineson and G. Hoyle. *Metal Treatment and Drop Forging*, 1956, **23**, 257-262.
- 15 I.S.I. Special Report No. 16, 1937, 124.
- 16 J. E. Garside, T. E. Rooney and J. J. J. Belli. *J.I.S.I.*, 1957, **155**, 93.
- 17 R. Pemberton. *The Analyst*, 1952, **77**, 287-292.
- 18 E. J. Vaughan and C. Whalley. *J.I.S.I.*, 1947, **155**, 535-562.
- 19 P. H. Scholes. *Metallurgia*, 1956, **53**, 129-131.
- 20 *Proc. of Tech. Sect. of The British Paper Board Manufacturers Association*, 1955, **28**, Part 3.

The Determination of Cobalt in Ferrous Alloys using a Chromatographic Separation

By D. G. Stern

Chemical Laboratory, Rotax, Ltd.

A method is described in which the ferrous alloy is dissolved in hydrochloric acid and oxidised with hydrogen peroxide, prior to separation of the cobalt from interfering elements chromatographically. 1-Nitroso-2-naphthol is used for the final precipitation.

THE standard method of determining cobalt, which involves one or two zinc oxide separations to ensure the removal of interfering elements, is satisfactory, but is not easy to carry out successfully. The method described in this paper, which depends on 1-nitroso-2-naphthol for precipitation of the cobalt after a chromatographic separation from interfering elements, cuts the time to complete a determination by 50%, and is much easier to carry out. Its use involves no sacrifice in accuracy.

Method

Apparatus

The absorption apparatus is a glass tube about $\frac{3}{4}$ in. diameter and 20 in. long, the upper end being somewhat wider to allow easy transfer of the material to it. The lower end is narrowed to a small diameter outlet which may be closed by a piece of polythene tubing with a screw clip. Alternatively, the

he column first, followed after a short gap by a bright blue band of cobalt. Allow elution to continue until all the yellow band has disappeared from the column, then collect the eluate in a 650 ml. conical beaker, continuing elution with solvent until all the bright blue cobalt colour is removed from the column. Any pale or bright green coloured bands which may appear above the cobalt can be ignored. Dilute to approximately 200 ml. with water. If two phases separate in the beaker, homogenise by dropwise addition of hydrochloric acid (s.g. 1.16).

Warm carefully to 70° C., keeping away from any naked flame. Add 1-nitroso-2-naphthol reagent, ensuring excess by allowing 1.5 ml. for each 1 mg. of cobalt anticipated in the sample. Digest at 70° C. for 1 hour, filter off the dark red precipitate on a pulp pad, wash with hot 2% hydrochloric acid and hot water and ignite at 800°-850° C.

$$\text{Cobalt \%} = \frac{\text{Weight Co}_2\text{O}_3 \times 73.44}{\text{Weight of sample}}$$

For Tungsten-bearing Ferrous Alloys—Weigh 0.1-1.0 g. of alloy into a small beaker, dissolve in 20 ml. conc. hydrochloric acid, oxidise by dropwise addition of nitric acid (s.g. 1.42), and then take down to dryness and bake for 30 minutes. Re-dissolve in 10 ml. conc. hydrochloric acid, allow to cool and continue as described above. There is no need to filter off the tungstic oxide as this will remain at the top of the column.

Interfering Elements

In addition to cobalt, 1-nitroso-2-naphthol also precipitates ferric iron, copper, palladium and, partially, chromium, molybdenum, tungsten, uranium, titanium, zirconium, lead, tin, silver and bismuth. With ferro-alloys, and in particular steels, elements present in large enough quantities to interfere are ferric iron, copper, chromium, molybdenum, titanium, tungsten and lead. These behave as follows:—

Ferric iron moves down the column first and is separated from the cobalt quite easily.

Copper moves more slowly and is therefore not quite so easy to separate, but is accounted for as described below.

Chromium, molybdenum and titanium move rather more slowly than cobalt, and therefore do not interfere.

Lead and tungsten remain at the top of the column, and do not confuse other separations.

To remove any copper contaminant from the cobalt oxide obtained after ignition of the 1-nitroso-2-naphthol complex, the black residue is dissolved in 10 ml. hydrochloric acid (s.g. 1.16), diluted with its own volume of water. Copper is then precipitated with hydrogen sulphide, filtered off and ignited to the oxide at 650°-800° C. This may be weighed directly or dissolved in dilute nitric acid and determined volumetrically by titration with iodine. Colorimetric or electrolytic methods may also be employed. The copper, calculated as oxide, CuO, may then be deducted from the weight of the cobalt oxide and copper oxide residue.

If the oxide precipitate appears contaminated with iron or chromium, or both, as indicated by a pale brown or green colour, the residue is dissolved in hydrochloric acid and 5 g. of solid ammonium chloride are added; the solution is then made ammoniacal, boiled, and allowed to stand for a few minutes. The precipitated

TABLE I.—COMPARISON OF RESULTS OBTAINED BY THE ZINC OXIDE SEPARATION AND THE CHROMATOGRAPHIC SEPARATION

Sample	Cobalt Found (%)	
	Double Zinc Oxide Separation	Chromatographic Separation
1	48.50	48.72
2	23.72	23.60
3	0.67	0.66
4	48.76	48.75
5	5.64	5.64
6	5.83	5.79
7	47.80	47.81
8	23.72	23.70
9	5.84	5.70

A Simple Instrument for the Comparison of Magnetic Permeabilities

By F. R. Burgess,* A.M.I.E.E.

The instrument described in this article has been developed for the determination of the magnetic permeability of low permeability materials. Its advantages include its portability and the fact that it can be applied to irregularly shaped pieces.

THE Company with which the author is associated makes castings and wrought products in a range of non-ferrous alloys for the engineering industry. Many of the products, particularly in the copper-base alloy field, are of a rather special character and demand the use of high-grade alloys in which qualities such as a high strength and high resistance to corrosion and erosion are sought. In particular cases there may be the additional requirement that the parts shall be "non-magnetic."

Now while the term "non-magnetic" as used by purchasers is possibly an elastic one, allowing in some instances of a deviation from a permeability value of precisely 1, it may not always be easy to provide all the qualities sought, including a low permeability, in particular cases. As examples, some of the aluminium bronzes and manganese bronzes exhibit definite magnetic properties, either because they contain iron or other ferro-magnetic elements, or for constitutional reasons. Some alloys are only very feebly magnetic, while others may be either feebly or more strongly magnetic depending on their thermal history. In particular cases alloys may show permeabilities of the order of 15 in weak fields, but these compositions are capable of being brought into a condition of low permeability by appropriate thermal treatment.

The need therefore arose to find a quick method of examining the magnetic state of cast and wrought parts using equipment which was portable and capable of being applied to irregularly shaped pieces without preparation. The original objective was to do no more than distinguish between parts having a high magnetic permeability and those in which the magnetic properties had been reduced to a low level, and in particular to check whether corrective thermal treatments had been effectively applied. The use of the instrument in a quantitative sense was a later development, but here again accuracy was only looked for with permeabilities of a low order (say 1-2).

The instrument designed to satisfy the above conditions is based on the general principle that the impedance of a coil will change when a material having a permeability other than unity is placed in the magnetic field set up by the coil.

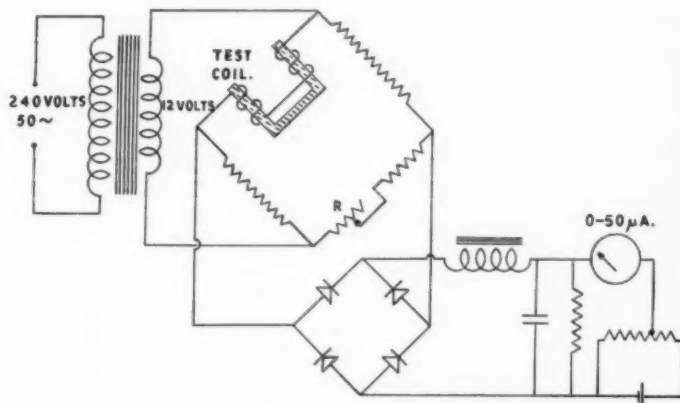


Fig. 1.—Circuit diagram of permeability tester.

Previous instruments¹ used for the measurement of magnetic properties of materials made use of this principle by having two identical coils in adjacent arms of an alternating current bridge circuit. The insertion of a specimen into one coil only, unbalanced the bridge and the out of balance voltage was indicated on a cathode ray oscilloscope. The instrument was calibrated, using suitable standards, and the relationship between the voltage indicated and the permeability of the material under test established. The instrument as normally constructed² is not portable and, since the material to be tested has to be placed inside a coil, the method is obviously not applicable to large and unevenly shaped castings or forgings.

Portable Instrument

The present instrument uses only one coil, the test coil, and this is wound on a U-shaped laminated iron core of high permeability. The coil forms one arm of a bridge network across which a nominally constant A.C. voltage is impressed. The material under test, when brought into contact with the open end of the core, completes the magnetic circuit and changes the impedance of the coil, unbalancing the bridge by an amount depending on the permeability of the material. Since we are here only concerned with low permeability materials, the degree of mechanical contact and hence of magnetic coupling between the specimen and the core of the test coil has relatively little effect on the change in flux produced; this enables the instrument to be used for measurements on unmachined and/or curved surfaces.

It will be seen from the circuit diagram (Fig. 1) that

* Metallurgical Research Laboratory, J. Stone & Co. (Charlton) Ltd.

the bridge is completed with three non-inductive resistors arranged to give a balance with the resistance of the coil, any residual out of balance voltage, due to the inductance of the coil, being cancelled in the micro-ammeter circuit by a battery and resistance. To use the instrument, the reading on the meter is reduced to zero by adjusting the resistance R , the test coil then being brought into contact with the metal under test and the meter reading noted. A previous calibration of the instrument using specimens of known permeability allows permeability values to be read directly from the meter, or from a calibration curve. It is important that the permeability of any "standards" used should be known at a field strength equal to that of the test coil, as permeability varies considerably with field strength.

If the supply voltage to the bridge changes, then the residual output voltage of the bridge will be changed and the meter will have to be reset to zero by adjusting R . The provision of a stabilised A.C. supply to the bridge is a possible refinement, but this is not a feature of the present instrument, as permeability indications have been found to be influenced only to a minor degree by input voltage changes.

Measurements on specimens are reproduced to within half a scale division, or $\frac{1}{50}$ of full scale deflection. As the instrument is calibrated with specimens of the same material as that to be tested, the accuracy depends on the accuracy of the standards and on such errors as may be introduced by differences in the size and shape of the standards and the parts being measured.

The values of components used in the instrument are not critical, and therefore no values have been given. The current through the coil depends on the resistance in the adjacent arm of the bridge, and the field strength

depends on the current: it will be seen that the supply voltage and bridge resistors must be chosen to suit the test coil.

To illustrate the point that the indications of the instrument are (within limits) independent of the degree of the mechanical contact, the results of a test with specially prepared specimens may be quoted. These specimens were 1 in. diameter bronze bars with a flat machined along their length. Readings were taken firstly with the curved surface and afterwards with the flat surface in contact with the flat surface of the poles of the core.

Specimen	Permeability Reading on Curved Surface	Permeability Reading on Flat Surface
1	1.4	1.4
2	6.3	7.0

It will be seen that in the range of permeabilities with which we are mainly concerned identical readings are obtained when contact is made with the round and the flat surfaces: in practice, provided that there is reasonable contact between pole faces and specimen, readings are independent of shape or surface finish. With materials of higher permeability there is some loss of accuracy, but this was of no serious concern for the purpose for which the instrument was intended: within its own field the instrument has proved a most useful inspection tool.

Acknowledgment

The author is indebted to the Directors of J. Stone & Company (Charlton), Ltd. for permission to publish this article.

REFERENCES

- 1 Convey & Russell, *Journal of Scientific Instruments*, **23**, 71 (1946)
- 2 *Journal of Scientific Instruments*, **21**, 201 (1944).

British Atomic Energy Displays

THE Board of Trade, in conjunction with the United Kingdom Atomic Energy Authority and in consultation with industry, will be organising two displays at Overseas Trade Fairs in Germany and Australia in 1957 to illustrate Britain's atomic energy programme.

The first of these will occupy about 3,000 sq. ft. at the Hanover International Trade Fair from April 28th to May 7th, 1957. This event is one of the world's most important engineering fairs, and is visited by large numbers of trade buyers and technicians from Germany and many other countries. The British exhibit has, therefore, been designed with the engineer rather than the layman in view. The stand will explain the reasons which have led Britain, with her growing needs for energy and limited resources of indigenous fuel, to pioneer the development of nuclear power reactors. Models, photographs and diagrams will show the part played by each of the various components in a nuclear generating station and the problems which have to be overcome in constructing a station such as Calder Hall as an example. A survey of Britain's other reactors will illustrate the extensive scale of the research behind the new programme announced by the Minister of Power, and the scope of this programme will be indicated visually; details will be available of the various firms which are co-operating in it. Possible lines of future development will be outlined, and it is expected that

one or more prominent British scientists working in these fields will visit Hanover during the fair. Technicians from the Atomic Energy Authority and from industry will be available on the stand to answer enquiries.

The second display will go to Australia and will cover basically the same ground, but will be mobile and will have a more general appeal. It will first be shown at the Sydney Industries Fair from July 22nd to August 3rd, 1957, where some British firms engaged in the atomics industry will have commercial exhibits on adjoining stands. It will be shown at the Royal Agricultural Show, Melbourne, from September 19th to 29th, and subsequently at Canberra, Perth, Adelaide and Brisbane. Arrangements are being planned for various forms of supporting publicity, while a representative of the Atomic Energy Authority will travel with the exhibit and be available to answer questions.

West Instruments Made in Britain

ORIGINALLY the entire line of West instruments was imported intact from the United States. Very soon, however, assembly was carried out over here, merely importing the patented elements and distinctive parts. Starting last month, most of the units are completely British made, a change which results in considerable economies, which are being passed on to the customer.

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